U.S. Army Corps of Engineers®

ILLUSTRATIONS OF ENVIRONMENTAL ENGINEERING FEATURES FOR PLANNING

Decision Support Technologies Research Program

December 1998

IWR Report 98-R-8

U.S. Army Institute for Water Resources
Technical Analysis and Research Division

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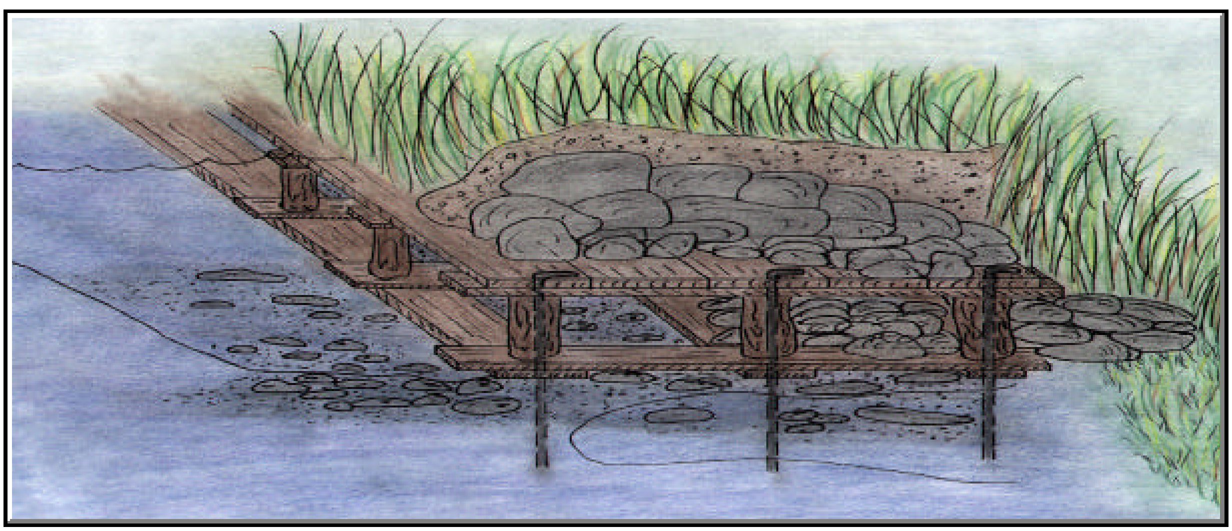
ILLUSTRATIONS OF ENVIRONMENTAL ENGINEERING FEATURES FOR PLANNING



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PREFACE

The work presented in this document was conducted as part of the Decision Support Technologies Research Program. The Program is sponsored by the Headquarters, U.S. Army Corps of Engineers and is assigned to the Water Resources Support Center, Institute for Water Resources. Mr. Michael Krouse is the Program Manager at the Institute for Water Resources. Mr. Robert Daniel, Planning Division, Mr. Jerry Foster, Engineering Division, and Mr. Harold Tohlen, Operations, Construction and Readiness Division, are the Headquarters' Program Monitors. Field Review Group Members that provide overall Program direction include: Mr. William Fickel of the Fort Worth District, Mr. Martin Hudson of the Portland District, Mr. Matt Laws of the Charleston District, and Ms. Pat Obradovich of the Portland District. This paper was prepared under the general supervision of Mr. Michael Krouse, Chief of the Technical Analysis and Research Division (TARD), Institute for Water Resources, and Mr. Kyle Schilling, Director of the Institute for Water Resources and Acting Director of the Water Resources Support Center.

This document evolved from the contributions of people, reports, books, and other handbooks which are listed in the reference and also from many WEB sites which are also listed in a separate appendix. We would like to acknowledge the many people from the various districts and divisions that took the time to submit photographs, drawings, illustrations and information to help put this document together. This document was prepared by Ms. Joy Muncy of the TARD.

We would like to thank the following people for their review and comment of this document: Bill Hansen, Ken Orth (now SPD), Darrell Nolton, and Lynn Martin, from IWR, David Derrick and J. Craig Fischenich from Waterways Experiment Station, Bob Daniel, Beverly Getzen, Bruce Wallace, Pete Juhle, John Bianco and Denise White from HQUSACE, Meg Burns and Jon Fripp from the Baltimore District, Pat Obradovich from the Portland District and Martin Hudson from the Portland District.

The illustrations of this document were drawn by Joy Muncy, Institute for Water Resources, Corps of Engineers. On the cover, the top left illustration is a training fence which was adapted from the Walla Walla District, Corps of Engineers. The bottom illustration is a lunker which was adapted from the book "Trout Stream Therapy" by Robert L. Hunt.

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CHAPTER I. - INTRODUCTION

BACKGROUND INFORMATION

The application of the Corps of Engineers' capabilities to ecosystem restoration needs and opportunities has increased considerably over the last decade and is expected to continue to increase. Not only is the Corps mandated to include environmental considerations throughout the various stages of Civil Works studies and projects, the Corps can participate in studies and projects specifically for the purposes of addressing environmental restoration objectives. The wide range of ecosystem restoration needs and opportunities demands diversification of the suite of engineering tools and management approaches used to address environmental restoration problems. Study managers and designers currently have little guidance available to help efficiently spark ideas on new and creative solutions.

Traditional engineering specifications are sometimes perceived as overly rigorous for environmental restoration projects, as the level of risk involved may be less than that, for example, associated with a flood damage reduction project. This is of particular concern as unnecessary rigor in design can drive up the cost of studies and projects making them cost prohibitive and inefficient.

Corps planners and designers have embraced the task of tackling ecosystem restoration problems, however, often they must "start-from-scratch" in formulating alternative approaches or designs. Considerable restoration work has been done within the Corps and by others, resulting in a wealth of information and experiences concerning ecosystem restoration, in spite of the relative newness of this field. A compilation and assessment of past or ongoing restoration efforts could serve as a useful tool for future Civil Works ecosystem restoration planning and design initiatives.

PURPOSE

The purpose of the document is to identify and describe examples of various environmental **engineering features** or **management measures** and their components. The document responds to a need expressed by various study managers, project managers, engineers, water resource planners, and others for descriptive information as to design and management measures applied to ecosystem restoration projects. The objective is to **stimulate** planners and others as to the types of management measures that are available. This document is not intended to be a design manual, but rather to provide sufficient information to stimulate plan formulation and assist planners in identifying what's out there and to "visualize" how an engineering feature(s) may be applicable to their project.

SCOPE

This document describes 64 engineering features and 15 other techniques. These engineering features, which are described in Chapter 2, can be used alone or often in combinations. The 15 other techniques, which are described in Chapter 3, focus restoration on a larger scale. These techniques entail broader activities than the engineering features described in Chapter 2. Basically the descriptions include: 1) what the structure is; 2) where they are usually built; 3) what materials are used in constructing the feature; 4) advantages and disadvantages of the feature; and 5) sources of the information and figures. The descriptions of most of these engineering features or management measures include either an illustration(s) or photograph(s).

The 79 engineering features and other techniques described in this document are in no way inclusive of all techniques available or being developed. This document should be considered a living document which will be updated periodically.

Note: The engineering features described and illustrated within this document were not formulated at the Institute for Water Resources. There is no intent to take credit for the engineering features described and illustrated in this document. This document simply compiles environmental engineering designs from numerous reports and other sources.

ORGANIZATION OF DOCUMENT

This document consists of four chapters and four appendices. The introductory chapter includes the background information, the purpose, scope, organization of the document, and a summary of engineering features with tables. Chapter 2 discusses 64 types of engineering features. Most of the features have an illustration or photograph along with a description. The chapter concludes by introducing a new management measure which was recently patented. Chapter 3 discusses 15 other types of techniques which cover broader activities than discussed in Chapter 2. Conclusions and recommendations for further work are presented in Chapter 4. The document concludes with Appendix A - Glossary, Appendix B - Reference Section, Appendix C - a listing of WEB sites used as References and other sites which were found to be complementary to this document, and Appendix D - Other Related Reports.

SUMMARY OF ENGINEERING FEATURES

The 79 engineering features and other techniques described in this document are grouped into the following categories:

- Bank treatment
- Instream practices

- Structures in ponds and lakes
- Coastal measures
- Other Techniques

Thirty four bank treatment measures are described ranging from bioengineering to harder-type measures. Except for the water control structure, the 22 instream practices use mainly stone, boulders, gravel, lumber, logs, trees, sandbags, and rebar in various combinations. The water control structure described is a concrete structure, constructed to control saltwater intrusion into a fresh water area. Three techniques are described which are normally used in ponds, lakes or wetlands that benefit waterfowl by providing nesting site alternatives. Five coastal type structures are also included in this document.

Fifteen other techniques are described which entail a broader type approach than the other engineering features. They are grouped in the following categories with the number of features described in (): Backwater Management (2); Channel Reconstruction (3); Stream Corridor Measures (2); Discharge Manipulation (3); Watershed Practices (3); and Other Methods (2).

The following Table 1 provides for each of the 79 engineering features and other techniques a quick check list of: **Outputs Provided**, **Stream Morphology Characteristics**, and **Inputs Needed**. Provided below is a brief description of each of the items in each grouping.

- **Outputs Provided**

  - *Shading* - Tree cover can be used to cause a temperature change in the stream.
  - *Nesting* - Trees/shrubbery for wildlife to nest or lunker structure for aquatic habitat to nest. To provide some sort of housing.
  - *Resting* - Behind a deflector for aquatic habitat to rest.
  - *Cover* - Overhanging logs to provide cover from predators.
  - *Spawning* - Spalls or rocks for aquatic habitat to use for spawning.
  - *Scouring*- Usually occurring from some sort of dam or boulder in high gradient streams in order to develop pools.
  - *Erosion Protection* - Stream bank protection and stream bed protection. To protect from sedimentation.

- **Stream Morphology**

    - *Width*- S-small - up to approximately 8 feet, M-medium - 8 to 20 feet, L-large - over 20 feet
    - *Grade of Stream* - L-Low Gradient, M-Medium Gradient, H-High Gradient. (Using Hunt's definition of Gradient where "L"-"M" is less than one (1) percent and "H" is one (1) to three (3) percent.
    - *Bank Grade* - L - 1V to 5H; M - 1V to 3H; H - 1V to 1H.

- **Inputs Needed**

    - *Hard (e.g., concrete)* - Using concrete, steel beams, etc. for construction.
    - *Live Plants, Cuttings and/or Seeds* - The technique calls for vegetation or can be used with other inputs.
    - *Natural Materials (e.g., rock, logs)* - The technique calls for the natural materials as all or part of the feature.
    - *Bioengineering* - The technique calls for bioengineering techniques.
    - *Costs*- L - Low (materials and labor are easily obtainable; use of volunteers); M - Medium (materials and labor may be less accessible, lot of time may be needed, may need specialty labor); H - High (materials and labor are less accessible; lot of time is needed; specialty equipment and labor is needed; delivery of goods is difficult).

TABLE 1. SUMMARY OF ENGINEERING FEATURES

ENGINEERING FEATURES	OUTPUTS PROVIDED							STREAM MORPHOLOGY					INPUTS NEEDED					
	SHADING	NESTING	RESTING	COVER	SPAWNING	SCOURING	EROSION PROTECTION	WIDTH S	WIDTH M	WIDTH L	GRADE OF STREAM	BANK GRADE	HARD (I.E., CONCRETE)	LIVE PLANTS, CUTTINGS AND/OR SEEDS	NATURAL MATERIALS (I.E., ROCK, LOGS)	OTHER MATERIALS (I.E., FIBER MAT, REBAR)	BIOENG	COSTS
BANK TREATMENTS																		
Bank Cover and Current Deflector	X	X	X	X	X			X	X		M	L-M		X	X	X	X	L
Bank Crib with Cover Log				X			X	X	X		M	L-M			X	X	X	L-M
Bank Shaping and Vegetating	X	X	X				X	X	X	X	L-H	L-M		X	X	X	X	L-H
Bioengineering and Its Techniques	X	X	X	X			X	X	X	X	L-H	L-M		X	X	X	X	L-M
Brushpacking (Branchpacking) and Brushlayering							X	X	X	X	L-H	L-M		X	X	X	X	L-M
Brush Bundles				X		X	X	X	X		M	L		X	X	X	X	L
Brush Mats				X		X	X	X	X	X	M-H	L		X	X	X	X	L
Cable Concrete							X	X	X	X	L-H	L-H	X	X		X		M
Cellular Confinement Systems							X	X	X	X	L-H	M-H	X	X	X	X		M
Coconut Fiber Roll, Coir Rolls, Coir Mats and Coir Netting							X	X	X	X	L-M	L-M		X	X	X	X	M
Dormant Posts or Dormant Cuttings							X	X	X	X	L-M	L-M		X			X	L
Erosion Control Blankets/Turf							X	X	X	X	L-H	L-H	X	X		X	X	M

TABLE 1. SUMMARY OF ENGINEERING FEATURES

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	SHADING	NESTING	RESTING	COVER	SPAWNING	SCOURING	EROSION PROTECTION	WIDTH S	WIDTH M	WIDTH L	GRADE OF STREAM	BANK GRADE	HARD (I.E., CONCRETE)	LIVE PLANTS, CUTTINGS AND/OR SEEDS	NATURAL MATERIALS (I.E., ROCK, LOGS)	OTHER MATERIALS (I.E., FIBER MAT, REBAR)	BIOENG	COSTS
BANK TREATMENTS, cont.																		
Fabriform® Erosion Control System							X	X	X	X	L-H	L-M	X			X		M
Gabions and Gabion (Reno) Mattresses							X	X	X	X	L-H	L-H	X	X	X	X		M-H
Grass Rolls							X	X	X	X	L-M	L-M		X	X	X	X	L-M
Hedge-Brush Layering	X						X	X	X	X	L-H	M-H		X	X	X	X	L-M
Joint Planting or Vegetative Riprap				X			X	X	X	X	L-H	M-H		X	X	X		M-H
Live Cribwalls	X						X	X	X	X	M-H	H		X	X	X	X	L-M
Live Fascines or Wattlings							X	X	X	X	L-M	L-H		X	X	X	X	L
Live Siltation		X		X			X	X	X	X	L-M	L-H		X	X		X	L
Live Staking							X	X	X	X	L-H	L-M		X			X	L
Log and Brush Shelter	X			X			X	X	X		L	L-M		X	X	X	X	L
Log Cribbing							X	X	X		L-H	L-M			X	X	X	L
Log, Rootwad and Boulder Revetment (Native Material Revetment)	X			X			X	X	X	X	M-H	L-M		X	X		X	L-M
Overhanging Bank Cover			X	X			X	X	X	X	L-H	M-H			X	X	X	L-M

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BANK TREATMENTS, cont.																		
Placement of Boulders			X				X	X	X	X	L-H	L-M			X			L
Riprap							X	X	X	X	L-H	L-H			X	X		M-H
Rootball or Rootwad Placement							X	X	X	X	L-H	L-M		X			X	L
Straw Rolls							X	X	X	X	L-H	M-H		X	X	X	X	L-M
Streambank Debrushing				X		X	X	X	X		M-H	L-M		X				L
Training Fences							X	X	X	X	L-H	L-H				X		M
Vegetated Geogrids				X			X	X	X	X	M-H	H		X	X	X	X	M-H
Vegetation/Revegetation	X	X		X		X	X	X	X	X	L-M	L-H		X			X	L-H
INSTREAM PRACTICES																		
Bendway Weirs			X			X	X	X	X	X	M-H	L-H			X			M
Boulder of Log Weir					X		X	X	X		M	L-M			X			L-M
Channel Block						X		X	X		M-H	L-M			X	X		L
Channel Constrictor				X		X		X			H	L			X	X		L
Cobble or Gravel Liners					X		X	X	X		M	L-H			X	X		L

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INSTREAM PRACTICES, cont.																		
Cross Channel Log and Revetments				X		X		X	X		H	L			X	X		L
Deflectors (Rock)	X				X	X	X	X	X		M-H	L-M		X	X		X	L-M
Deflector (Single Wing)						X		X	X	X	L-H	L-M			X	X		L
Deflector (Double Wing)						X		X			L	L-M			X	X		L
K-Dam						X		X	X		H	L-M			X	X		L
Log Cover (Whole, Half, & Slab)	X		X	X				X	X	X	L-H	N/A			X	X		L
Lunker Structure	X	X	X	X	X		X	X	X		H	L-M		X	X	X		L
Rock Spur Dikes							X	X	X	X	L-H	L-M		X	X			M
Wood Spur Dikes							X	X	X	X	L-M	L-M		X		X		L-M
Sky-Hook Bank Cover				X			X	X	X		L-M	L-M		X	X	X		L
Tip Deflector				X				X	X		L	M			X	X		L
Tree Cover	X	X	X	X	X	X	X		X	X	M	L-M			X	X		L
Tree-Drop Deflector and other Mid-channel Deflectors			X			X	X	X	X	X	M	L-M			X	X		L

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INSTREAM PRACTICES, cont.																		
Vortex Rock Weir with Floating Logs	X			X	X	X	X		X		M	L			X	X		L-M
"W" Rock Weir				X	X	X				X	M-H	L-H			X			L-M
Water Control Structure	Water Control							X	X	X	L-M	L-H	X			X		M-H
Wedge Dam						X		X			H	L-M			X	X		L
NESTING STRUCTURES																		
Earth Filled Concrete Culverts for Waterfowl Nesting		X	X					Ponds, Wtlnds			N/A	N/A	X	X		X		L-M
Islands for Nesting Waterfowl		X	X					Ponds, Wtlnds			N/A	N/A			X			M
Round Hay Bales		X	X					Ponds, Wtlnds			N/A	N/A		X	X	X		L
COASTAL MEASURES																		
Breakwaters							X					L-M			X	X		M
Jetties							X					L-M			X	X		M
Bulkhead							X					M	X		X	X		M-H

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COASTAL MEASURES, cont.																		
Seawalls							X					M	X		X	X		M-H
Groins							X					L-M			X	X		M
OTHER TECHNIQUES																		
Backwater Management																		
Sediment Basins	X	X	X	X	X	X	X	X	X		M-H	L-H	X	X	X	X		M
Water Level Control	Water Control							X	X	X	L-M	L-H	X			X		M-H
CHANNEL RECONSTRUCTION																		
Impoundment of Cutoff Bendways	X	X	X	X	X	X		X	X	X	L-H	L-M	X	X	X	X		M
CHANNEL RECONST, cont.																		
Maintenance Hydraulic Connections	X	X	X	X	X	X	X	X	X	X	L-H	L-H	X	X	X	X	X	M
Stream Meander Restoration	X	X	X	X	X	X	X	X	X	X	L-H	L-M		X	X			M-H
STREAM CORRIDOR MEASURES																		
Livestock Exclusion or Management	X	X	X	X	X	X	X	X	X	X	L-H	L-H	X	X	X	X		M
Riparian Forest Buffer	X	X	X	X	X	X	X	X	X	X	L-H	L-H		X			X	L-M

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DISCHARGE MANIPULATION																		
Flow Regime Enhancement						X	X	X	X	X	L-H	L-H	X	X	X	X	X	M
Flow Temperature Management	X	X	X	X	X	X	X	X	X		L-H	L-H		X	X		X	L-M
Flushing for Habitat Restoration					X	X	X		X	X	L-H	L-H	X			X		L-M
WATERSHED PRACTICES																		
Agriculture	See Table 3, Page 142-143							X	X	X	L-H	L-H	X	X	X	X	X	M-H
Forest Land	See Table 4, Page 147-148							X	X	X	L-H	L-H	X	X	X	X	X	M-H
Urban Areas	X	X	X	X	X	X	X	X	X	X	L-H	L-H	X	X	X	X	X	M-H
OTHER METHODS																		
George Palmiter Technique	X	X	X	X	X	X	X	X	X	X	L-H	L-H		X	X	X		L-M
Stream Obstruction Removal-SORG	X	X	X	X	X	X	X	X	X	X	L-H	L-H		X	X	X		L-M

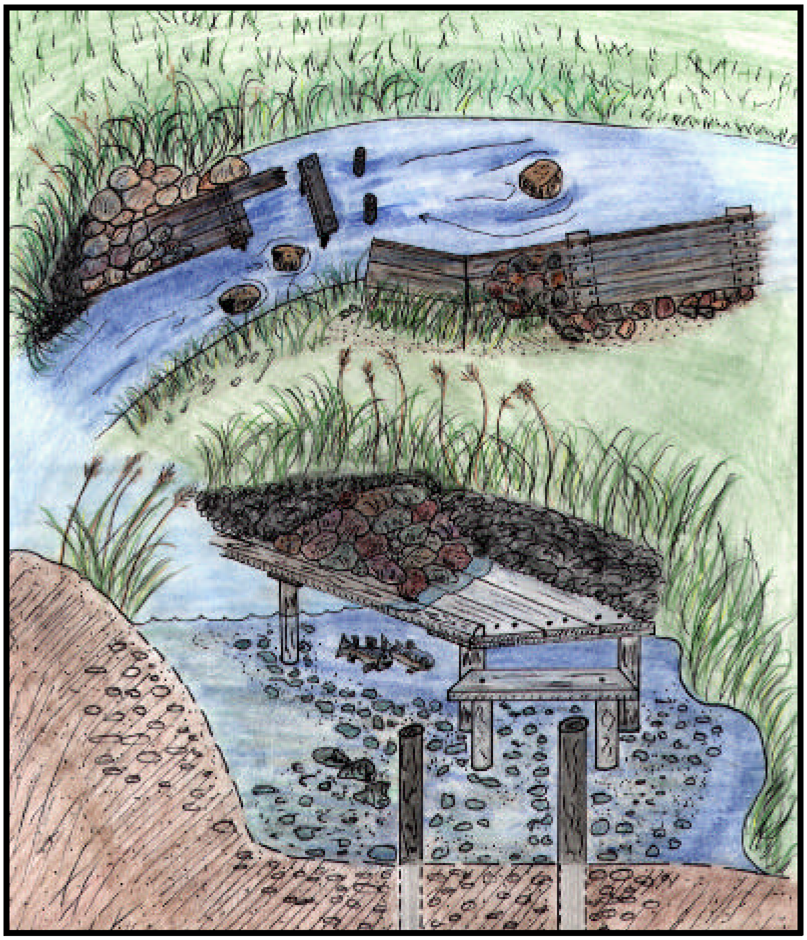
CHAPTER II. ENGINEERING FEATURES

Included in this chapter are 64 engineering features. These are listed alphabetically under the following headings:

- Bank Treatment (pages 14 - 88);
- Instream Practices (pages 89 - 115);
- Structures in Ponds, Lakes and Wetlands (pages 116 - 121);
- Coastal Measures (pages 122 - 129)

BANK COVER AND CURRENT DEFLECTOR
with SANDBAG AND GEOWEB® BANK COVER.
(Information extracted from Hunt's "Trout Stream Therapy.")

For low or moderate stream gradients, this type of structure is constructed similarly on opposite sides of the stream to provide two purposes: 1) deflecting flow to create pools and 2) providing habitat cover. Aerial and side views of the bank cover and current deflector are illustrated in Figure 1.

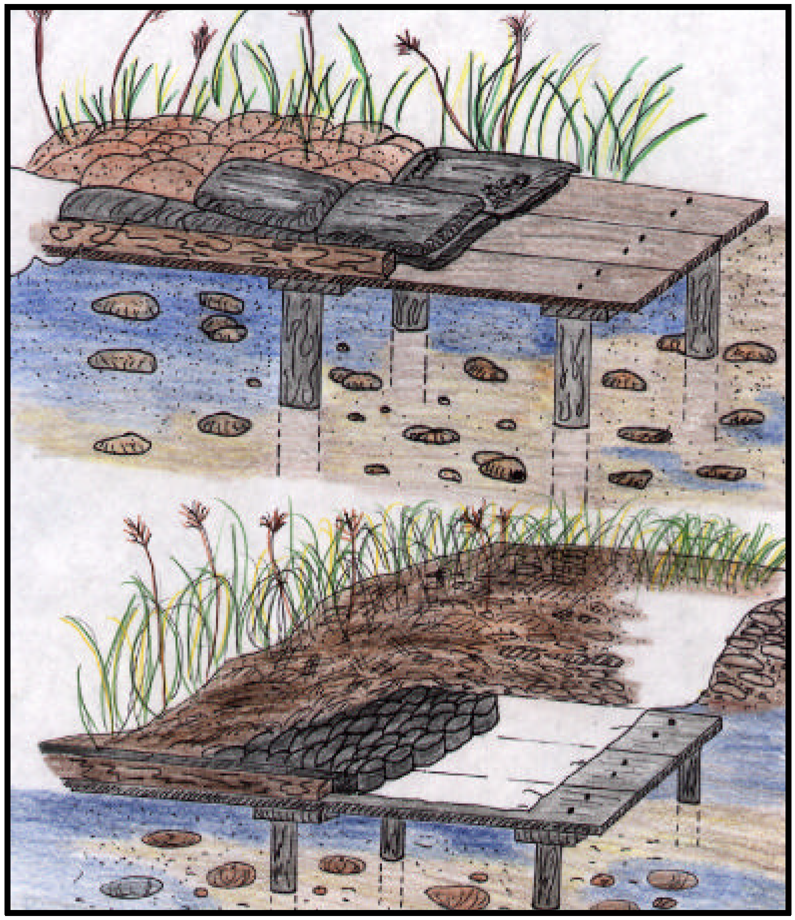


Bank Cover and Current Deflector **Figure 1**
adapted from "Trout Stream Therapy"

Construction of this structure starts with driving pairs of five (5) foot-long wooden pilings into the stream bottom using pressurized jets of water along the outside bend. Nail stringer planks of green-cut hardwood underwater to each pair of pilings at right angles from the natural streambank. Next, nail green-hardwood planks on top of the stringer planks and parallel with the natural streambank to complete an underwater wooden platform. After this stage of construction is completed, the structure should be underwater. The platform width will depend on the degree of stream channel narrowing that is desired, which is usually three to five feet. The streambank side of the structure should be filled with riprap or stones to establish a wall. The top of the structure should be covered with a stone mix and soil to produce a natural appearance. Sod and/or native vegetation should be used as top-dress.

Sufficient depth is assured by building the structures sequentially along the contours of the current-bearing banks of the stream. Slightly overlap the downstream end of the one structure (its current deflector portion) and the upstream end of the next structure on the opposite side of the channel as Figure 1 illustrates. Pools are scoured under each of these structures as the stream meanders downstream.

Where riprap, field stones or quarried rocks are not available, or they are difficult to transport to the stream, two substitute processes have been designed to build up new stream banks on the wooden platforms supported by pilings. One procedure utilizes polyethylene sandbags (16 inches x 29 inches) that are filled on site with stream bed materials and piled two (2) rows deep and two (2) rows high along the outside edges of the platforms. The bags and platforms are then covered with dirt and seeded, or covered with clumps of field sod. A completely natural appearance is restored usually after one (1) or two (2) growing seasons. This is illustrated in Figure 2.



Sandbag and GEOWEB® Bank Cover **Figure 2**
adapted from "Trout Stream Therapy"

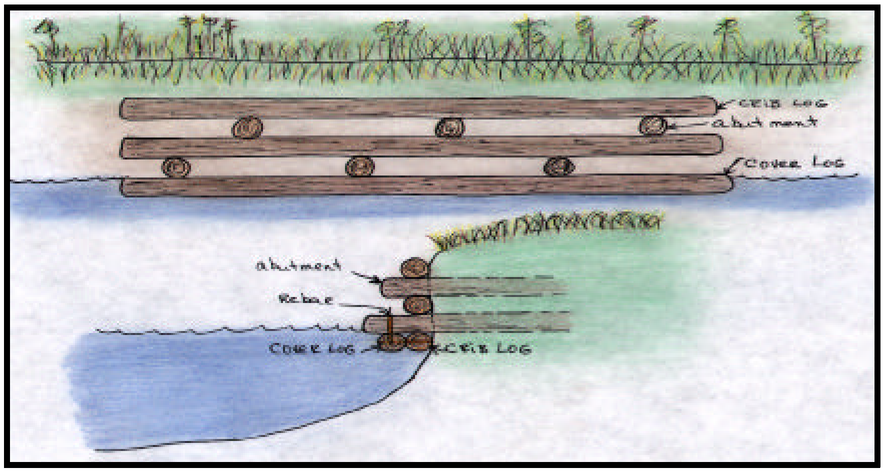
The second procedure, which provides a substitute for stones, involves the use of a commercially known product incorporating 8' x 4' x 8" polyethylene grids consisting of a series of honeycomb cells known as GEOWEB®. To provide a water-resistant seal and to prevent erosion, a sheet of roadbase fiber mat is laid on top of the wooden platform prior to placement of GEOWEB®. The fibermat is extended back and up the contour of the old streambank and then covered over with dirt and sod to stabilize the bank and tie in a natural-looking contour profile between the old and new streambanks. The honeycomb cells are filled with streambank material and finished with sod and/or native vegetation. This is also illustrated in Figure 2.

BANK CRIB WITH COVER LOG.

(Information obtained from the United States Department of Agriculture's (USDA) Forest Service and Gray/Sotir "Biotechnical and Soil Bioengineering Slope Stabilization.")

The bank crib with cover log is used to protect unstable banks, at the same time providing excellent overhead cover for fish. This structure can be used in any area with a suitable streambank. Figure 3 illustrates this technique.

"A crib is basically a box-like structure formed by joining a number of cells together and filling them with soil or rocks to give them strength and weight in order to form a gravity wall. The structural members in most crib walls are assembled "log cabin" fashion to form a cell." (Gray/Sotir)



Bank Crib with Cover Log **Figure 3**
adapted from the Forest Service - USDA

The design is a simple crib with abutment logs extending as far back into the bank as necessary to assure structure stability (four (4) to six (6) feet in stable soils and 10 feet or more in unstable soils). The lower abutment logs should be near water level and should extend 18 to 24 inches from the bank. The cover log can then be fastened to the crib log and the lower abutment. The structure can be from one (1) to several logs high, depending upon bank height. Cover logs can also be attached with cable to gabion mats serving the same purpose.

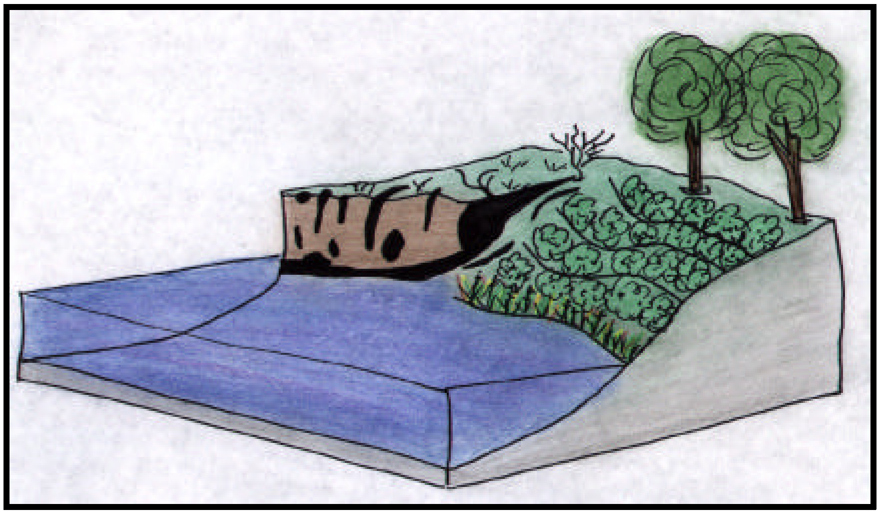
The design accomplishes two (2) objectives. It insures bank stability and creates excellent cover at the same time. The only materials required are logs on site and 5/8-inch rebar to join the logs. Installing the structures is fairly time-consuming, due to the amount of digging required. One crew should be able to install 20 to 30 feet of crib (two (2) crib logs high) per day if logs are reasonably close to the site.

For further information and design standards on log cribbing and other types of cribbing, refer to Gray/Sotir (1996), Federal Highway Administration (1974), American Wood Preservers Institute (1981), Hilfiker (1972), and Schuster et. al (1973) in the Reference Section, Appendix B.

BANK SHAPING AND VEGETATING.
(Information extracted from "Interagency Stream Corridor Restoration Handbook.")

Bank shaping involves excavating and filling the raw eroded streambank to the minimum side slope which is stable for the soil materials, moisture conditions, planned vegetation, bank loading conditions, and hydraulic exposure of the site. Bank shaping also includes placing topsoil and other materials needed for sustaining plant growth. Vegetating includes the selection and planting of appropriate plant materials. Bank shaping and vegetating is one of the least intensive approaches to restoration of the streambank and is often a preparatory step for other bank stabilization techniques. Figure 4 illustrates this method.

Bank shaping and vegetation is most successful on streambanks along reaches where flows are within the natural ranges for the area, and where moderate erosion and channel migration are desirable. If a stable bank is required, a toe revetment may be needed. It is becoming apparent from lessons learned that some kind of toe revetment is necessary with vegetation and bioengineering projects.



Bank Shaping and Vegetation **Figure 4**
adapted from "Stream Corridor Restoration Handbook"

This method should be used in conjunction with other protective practices when the flow velocities exceed the tolerance range for available plants, and where erosion is occurring below base flow levels. Banks which are experiencing mass movement should be stabilized prior to shaping and vegetating.

The guidelines for this method are described in the following paragraphs.

Properties such as streambank soil materials, probable groundwater fluctuation, and bank loading conditions need to be determined. Select a side slope which falls within recommendations for these properties. A professional should be consulted if conditions do not fit within these recommendations or there are other unusual circumstances.

Check other stable reaches of streambank along the stream or in neighboring watersheds for appropriate plant materials, similarity of soil materials, loading conditions, groundwater fluctuations, side slope, channel slope and other features.

Perform a hydraulic analysis of the stream reach. Determine bank full velocities that will occur along the streambank. Select native plant materials that are suited to the velocity regime and other site conditions or have shown success along other neighboring, similar reaches. Consider a variety of plant species.

The lower slope segments can be planted with flood tolerance species while upland species may be more suited to the better drained, upper slope. Select species which will blend during flow and withstand ice loading and abrasion. In dry regions, choose species which can root to the available groundwater level.

Again, consider toe protection below normal water level to protect the toe of the slope.

If frequent high water is likely after planting, consider applying a brush mattress, excelsior, or other protective covers to reduce the risk of losing the vegetation before establishment.

Schedule shaping works to end during the planting windows for the selected vegetation and to occur during periods which will not interfere with key aquatic species reproduction.

Divert flow away from the streambank by installing silt fences or other devices to keep construction generated sediment from entering the stream.

Salvage all topsoil by applying to the slope surface as a planting medium.

Plant, seed, fertilize and mulch according to recommendations. Follow with periodic supplemental water if needed to assure establishment.

BIOENGINEERING AND BIOENGINEERING TECHNIQUES.

(Information obtained from the EPA's Office of Wetlands, Oceans and Watersheds, Derrick from Waterways Experiment Station, and extracted from "Erosion Draw.")

Bioengineering refers to the installation of living plant material as a main structural component in controlling problems of land instability where erosion and sedimentation are occurring. Bioengineering methods use large, local cuttings (e.g., willows, cottonwoods.) This ensures that the plant material will be well adapted to site conditions. The foremost objective is for the natural encroachment of a diverse plant community to stabilize the streambanks through development of a vegetative cover and a reinforcing root matrix. The practice brings together biological, ecological, and engineering concepts to produce living, functioning systems to prevent erosion, to stabilize slopes and to enhance wildlife habitats (Erosion Draw).

Bioengineering techniques are used to prevent erosion on upland slopes and to protect streambanks and channels against wave erosion in the coastal zones. These biotechnical earth support methods can also be utilized to provide slope stability (Erosion Draw).

Conditions needed for a successful bioengineering project are (Derrick, 97):

- Sunlight
- Suitable soil (permeability, ph level)
- Stable slope
- Water (plant requirements and tolerance to submersion)
- Plant nutrients
- Biological knowledge of plant
- Knowledge of a how and when to plant (only when dormant)
- Where plants are found naturally

Soil bioengineering techniques are generally applicable for:

- Slopes to prevent surface erosion
- Cut and fill slope stabilization
- Shallow mass wasting
- Gully repair
- Streambank stabilization
- Shoreline stabilization
- Watershed rehabilitation

The following are planning considerations for bioengineering techniques (EPA):

- Soil bioengineering generally requires minimal access for equipment and workers and causes relatively minor site disturbance during installation. These practices are therefore considered appropriate for environmentally sensitive areas, such as parks, woodlands, riparian areas and scenic corridors where aesthetic quality, wildlife habitat and similar values may be critical.

- In bioengineering, the plant material in itself may provide both the structural and vegetative components of the design. For example, in willow wattles, live staking and brushlayering the woody material is used to provide initial structural protection and later, vegetative cover.

- Bioengineering systems are often more cost effective than the use of vegetation or structural solutions alone. Using indigenous materials accounts for some of the cost effectiveness because plant costs are limited to labor for harvesting, handling and the direct costs of transporting plant material to the site.

- Bioengineering systems are most effective when installed during the dormant season, usually late fall, winter or early spring. Constraints on planting times or availability of the required quantities of suitable plant materials during allowable planting times may limit the usefulness of bioengineering methods.

- Bioengineering systems are strong initially and grow stronger with time as the vegetation becomes established. Bioengineering systems may withstand heavy rainfalls immediately after installation. Even if vegetation dies, its plant material and surface residue continues to play an important protective roll during vegetation establishment.

- Soil bioengineering is useful on small, highly sensitive or steep sites where the use of machinery is not feasible.

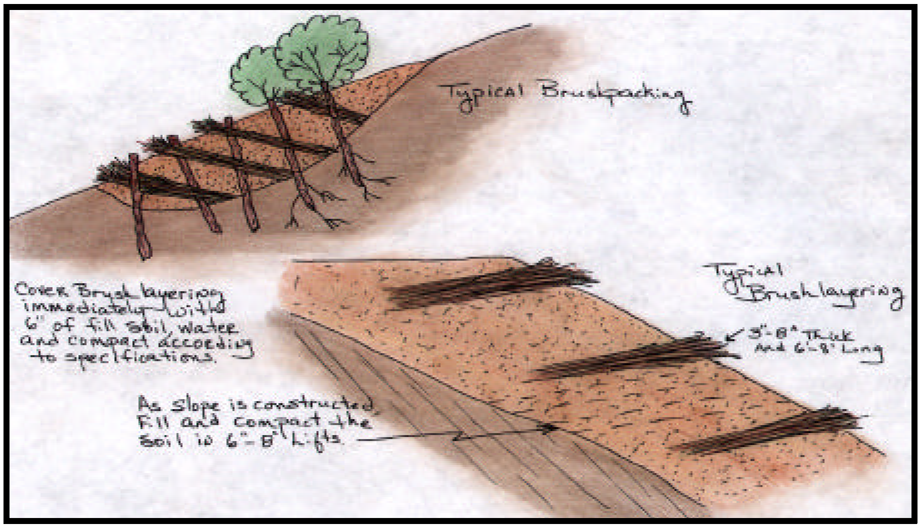
- Bioengineering practices are limited by the available medium for plant growth-rocky or gravelly slopes may lack sufficient fines or moisture to support plant growth or hard pans may prevent the required root growth.

- Choose plant materials that are adapted to the site conditions. Local stands of willow or other suitable species are already well suited to the climate, soil conditions and available moisture and they make good candidates for survival.

- When choosing live willow material for bioengineering applications, remember that young (less than one (1) year old) wood or suckers will often sprout easier under optimum conditions, but healthy, older wood (one (1) to four (4) years old) has greater vegetative (energy) reserves necessary to consistently sprout and the older wood is much stronger. If possible, mix younger wood with older wood for bioengineering application such that a majority of the material is one (1) to four (4) years old.

BRUSHPACKING (BRANCHPACKING) and BRUSHLAYERING. *(Information obtained from the EPA's Office of Wetlands, Oceans and Watersheds and extracted from "Erosion Draw".)*

In a brushlayering system, cuttings or branches of easily rooted tree species are layered between successive lifts of soil fill to construct a reinforced slope or embankment. These live branch cuttings may range from 3/4 inch to two (2) inches in diameter. The brushlayering branches, especially after rooting, reinforce slopes by serving as tensile inclusions which provide frictional resistance to sliding or other types of displacement. The protruding brush retards runoff and reduces surface erosion. Other terms for brushpacking are branchpacking and trenchpacking. Figure 5 illustrates this system (Erosion Draw).



Brushlayer and Brushpacking **Figure 5**
adapted from "Erosion Draw"

Brushlayering performs several functions for erosion control, earth reinforcement and slope stability (EPA):

- Breaking up the slope length into a series of shorter slopes separated by rows of brushlayer.
- Reinforcing the soil with the unrooted branch stems.
- Reinforcing the soil as roots develop, adding significant resistance to sliding or shear displacement.
- Providing slope stability and allowing vegetative cover to become established.
- Trapping debris on the slope.
- Aiding infiltration on dry sites.
- Drying excessively wet sites.
- Adjusting the site's microclimate, thus aiding seed germination and natural regeneration.
- Redirecting and mitigating adverse slope seepage by acting as horizontal drains.

The following points should be considered when planning this type of system (Erosion Draw):

- Plant material harvest and installation should be performed during the dormant season, which is usually late fall to early spring.
- Use site reconnaissance to identify willow species, growth form, soil and site conditions on adjacent sites and compare their conditions to the construction site. Planting will be more successful as the soil, site conditions and species selected match stable and vegetated nearby sites.
- The ideal plant materials for wattling are those that: 1) root easily; 2) are long, straight and flexible; and 3) are in plentiful supply near the job site. Willow makes ideal wattling material. Some species of Baccharis, Cornus, and Populus also have very good rooting ability.
- Choose plant material adapted to the site conditions and confirm the availability of plant material that will be used on site before construction begins.
- When choosing live willow material for bioengineering applications, remember that young (less than one (1) year old) wood or suckers will often sprout easier under optimum conditions but healthy, older wood (one (1) to four (4) years old) has greater vegetative (energy) reserves necessary to consistently sprout, and the older wood is much stronger. If possible, mix younger wood with older wood for the bioengineering application such that a majority of the material is one (1) to four (4) years old.
- Cuttings should be soaked for a minimum of 24 hours.
- Willows have several different growth forms, from shrubs to large trees. Small to medium sized shrub-type and rhizomatous or creeping-type willows are used for planting channel banks. Upland willow species are found in relatively dry areas and should be used on similar sites. Tree-type willows are selected for the upper bank and flood plain area.
- If branch cuttings are not pre-soaked, then they shall be harvested no earlier than 48 hours prior to installation. Cuttings must be kept moist and cool at all times between cutting and installation therefore, all cuttings need to be thoroughly wet and covered with moistened wrapping before being transported.
- Construction personnel shall be made aware that brushlayering uses live plant material and must be treated as such.
- Spacing between the brushlayers is determined by the erosion potential of the slope (i.e., soil type, rainfall, and length and steepness of the slope). Spacing may be from three (3) to eight (8) feet. On long slopes, brushlayer spacing should be closer at the bottom and spacing may increase near the top of the slope.
- Steep slopes should not exceed, approximate 30 feet in slope length. Reinforced earth design guidelines suggest that the slope height should not exceed three (3) times the width of the reinforced volume.

The construction considerations are as follows (Erosion Draw):

- Cuttings shall be harvested and planted when the willows, or other chosen species, are dormant. This period is generally from late fall to early spring.

- Choose plant materials that are adapted to the site conditions from species that root easily.
- Branch cuttings shall be four (4) to eight (8) feet long, 3/4 to two (2) inches diameter.
- Pre-soak cuttings for a minimum of 24 hours before installing.
- The surface of the bench shall be sloped so the outside edge is higher than the inside so the butt ends angle down slightly into the slope.
- Place branch cuttings, three (3) to eight (8) inches thick, in a crisscross or over lapping configuration. The growing tips shall protrude six (6) to 12 inches from the slope face with the butt end dipping into the slope.
- Immediately cover brushlayer with six (6) inches of fill soil and compact according to construction specifications. Water the soil cover immediately to wet the cuttings and achieve adequate compaction.
- Earth moving equipment shall not travel directly over the cuttings. Six inches of soil must be maintained between the brushlayer in successive lifts, maximum six (6) to eight (8) inches deep.
- Fill and compact the soil placed above the brushlayer in successive lifts, maximum six (6) to eight (8) inches deep.
- Install the next brushlayer three (3) to eight (8) feet above the previous row.
- Seed and mulch slope. Shallow slopes, generally 3H:1V or flatter may be seeded and mulched by hand. Steeper slopes should have seed applied hydraulically and the mulch shall be anchored with tackifier or other approved methods.

CABLE CONCRETE.

(Information extracted from International Erosion Control Systems.)

Cable Concrete is a precast articulating concrete block mat system. It consists of pyramidal shaped concrete blocks interwoven with stainless steel cable, underlaid with a durable geotextile fabric. These characteristics allow for flexibility and ease of installation. This system allows water permeability, vegetative growth, contour flexibility, subsoil confinement and long term control of erosion. Figure 6 shows a photograph of Cable Concrete used as channel protection.

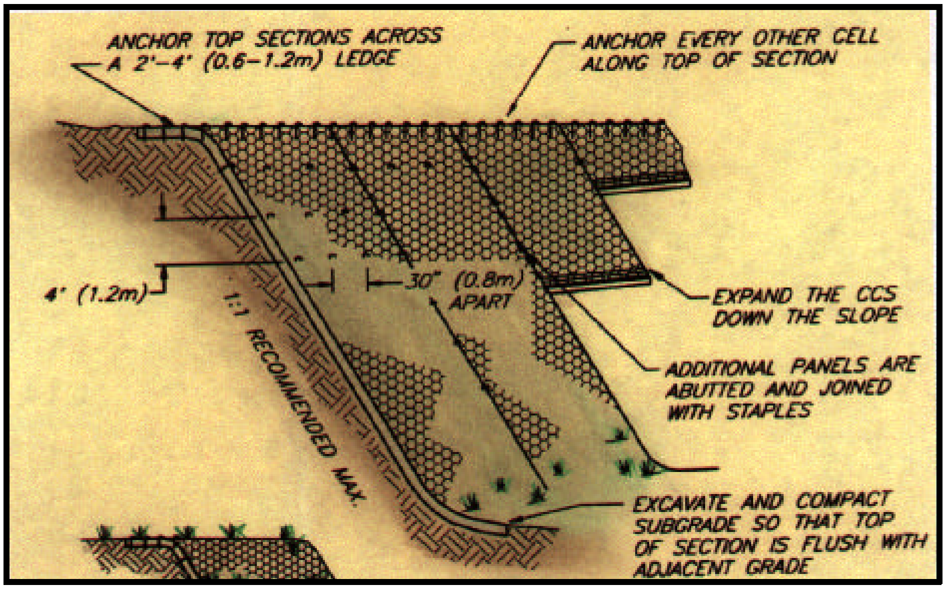
Cable Concrete **Figure 6**

adapted from International Erosion Control Systems

- **Stability.** Hydraulic conditions and flow velocities determine the block size and layout design needed to stabilize the erosive forces. The Cable Concrete mats, with the interwoven cable and mat to mat clamping, become one homogeneous control system. Cables are precast through each block, assuring both lateral and vertical stability.
- **Flexibility.** The pyramidal shape of the blocks provides for large angular variability. This flexibility allows the system to adapt to abrupt changes in grade contours.
- **Permeability.** The open area of the mats allows for sufficient transfer of water between the subgrade and the system surface. The attached geotextile fabric allows for relief of hydrostatic pressure without permitting migration of subgrade fines.
- **Vegetation.** Native and exotic grasses, broadleaf plants and shrubs will grow in the open area of the mat, if desired. Its has a smooth surface to allow for easy access by pedestrians and vehicular traffic, and affords easy maintenance of vegetation. Plants' root system actually enhance the stability of the system over the years. Because the cables are precast into the system, blocks can be removed for larger plantings without compromising the integrity of the system.
- **Reusable.** The cables of the mat allow for use as a temporary erosion control material, for construction traffic or emergency situations. The mats can then be lifted to more permanent placement elsewhere or put into storage for the next project.

CELLULAR CONFINEMENT SYSTEMS (CCS).
(Information extracted from "Erosion Draw.")

A cellular confinement system (CCS) is a three-dimensional honeycomb earth-retaining structure used to mechanically stabilize the surface of earth and fill slopes. CCS is a permanent erosion control practice intended to stabilize steep slopes. Figure 7 illustrates this system. The expandable panels create a cellular system that confines topsoil infill, protects and reinforces the plant's root zone, and permits natural subsurface drainage. The honeycomb shaped cells encapsulate and prevent erosion of the infill material. The cellular confinement systems are used for:



Cellular Confinement System **Figure 7**
obtained from "Erosion Draw"
John McCullah

- Revetments - by infilling the cells with rock, gravel, or topsoil which can provide an alternative to hard armor revetment systems.
- Erosion control on steep slopes - cells can be infilled with soil and vegetated or infilled with granular materials for sterile arid regions. Slopes as steep as 1H:1V can be treated with cellular confinement systems.
- Flexible channel lining systems - either vegetated or rock filled.
- Framework for earth retaining structures.
- Road stabilization - cells confine and reinforce select fill materials, thereby increasing load-bearing capacities.
- Temporary low-water stream crossings.

Site Preparation:

- The surface of the slope should be leveled, with stones and debris removed. Gullies should be filled and well compacted. Major obstacles such as boulders can be left in place. Simply cut out panel around them.

- Following excavation and fill placement operations, shape and compact the subgrade surfaces to the designed elevations and grades.
- Excavate the area so that when cellular confinement systems are installed, the top of the section is flush with or slightly lower than the adjacent terrain or final grade.
- Remove unstable subgrade soils when required and install geotextiles underlayer if specified.

Installation:

- Anchor the CCS sections at the top of the slope across a two (2) to (4) foot ledge. Expand and stretch the cellular confinement system down the slopes.
- Type of anchors and frequency of anchoring will depend on site conditions. Typically, every other cell across the top section is anchored with J-pins or other suitable anchor devices. This anchoring pattern is repeated every six (6) feet down the slope.
- The cells should be anchored securely in order to prevent deformation of the panel while backfilling. Depending on the slope angle and fill soils involved, intermediate anchorage will be necessary on some interior cells in order to limit sideways deformation, insure stability and avoid overloading the upper sections.
- Additional panels are abutted together and joined with staples, hog rings or other suitable fasteners.

Infill Placement:

- Place the fill material in the expanded cells with suitable equipment such as a back-hoe, front-end loader or conveyer.
- Limit drop height to three (3) feet.
- On steep slopes, infill from the crest to the toe to prevent displacement and deformation of the cellular confinement system.
- Overfilling and compacting of the infill depend on type and consistency of material and the depth of the cells. Generally:

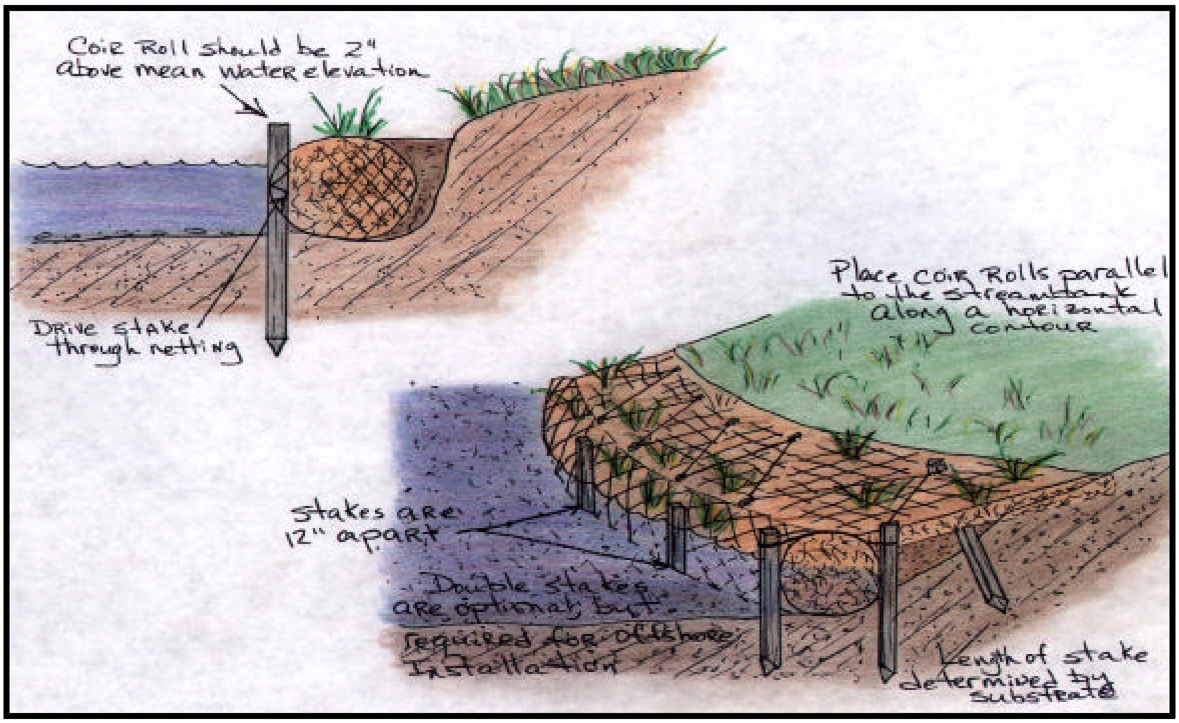
    - Overfill screened topsoil one (1) to two (2) inches and lightly tamp or roll to leave soil flush with the top edge of the cell wall:
    - Overfill loose granular materials one (1) inch and compact until infill material is flush with the top edge of the cell walls.

Surface Treatments:

Apply surface treatments (hydraulic planting, permanent seeding) following the placement of infill.

COCONUT FIBER ROLL, COIR ROLLS, COIR MATS AND COIR NETTING.
(Information extracted from "Erosion Draw.")

Coconut-fiber rolls are cylindrical structures composed of coconut fibers bound together with twine woven from coconut material as illustrated in Figure 8. These rolls are most commonly available in 12 inch diameter by 20 foot lengths. The rolls are staked near the toe of the streambank slope, and dormant cuttings or rooted plants can be inserted into incises, cut into the material. Coconut-fiber rolls are used to protect slopes from shallow slides or undermining, while trapping sediment which encourages plant growth within the fiber roll. The



Coir Roll and Coir Mat **Figure 8**
adapted from "Erosion Draw"

rolls provide the added advantages of flexibility to mold to the existing curvature of the streambank, and require little site disturbance.

Coconut-fiber rolls are used where moderate toe stabilization is required in conjunction with restoration of the streambank, and the site allows for only minor disturbance. Coconut-fiber rolls provide an excellent medium for promoting plant growth at the water's edge. They are not appropriate for sites with high velocity flows or large ice build up.

As with any type of manufactured or processed material, coconut-fiber rolls can be expensive. Coordinate the installation of the coconut-fiber rolls with other bank treatments. The rolls are a manufactured item, and should be ordered well in advance of the work. Delivery should be coincided with obtaining plant materials.

Excavate a shallow trench at the toe of slope to a depth slightly below channel grade. Place the fiber roll in the trench. Drive 2" x 2" x 36" hardwood stakes on both sides of the roll at two (2) foot to four (4) foot spacing depending upon the anticipated velocities. The top of stakes should not extend above the fiber roll. As an option, 1/4" rope can be laced across the top of the fiber roll and secured from stake to stake. Backfill with soil behind the roll to smooth fit with the existing slope.

As conditions permit, rooted herbaceous plants or dormant cuttings should be installed in the coconut fiber. Install appropriate vegetation or bioengineering systems upslope of the fiber roll. A coir mat can also be installed upslope for more stability.

Coir Rolls and Coir Mats. Coir rolls and coir mats are manufactured from coconut fibers and are frequently used as the structural and rooting medium components of bioengineering systems. Coir rolls and coir mats are commonly used for streambank stabilization and shoreline protection. These bioengineering components provide immediate erosion control while also providing a stable medium to support the growth and development of plants. The coir (coconut fiber) material is natural, long lasting, and has high tensile strength. The fiber material can replace commonly used structural components such as rocks, riprap or logs. The coir rolls and mats can then be planted with appropriate vegetation. The fiber rolls and mats accumulate sediment while the plants grow and the root develop. Eventually the coir material biodegrades and the cohesive strength of the root systems and flexible nature of the plants become the primary stabilizing element.

Soil bioengineering techniques utilizing coir rolls and coir mats are generally appropriate for:

- Streambank stabilization,
- Shoreline stabilization,
- Wetland mitigation or restoration, and
- Other riparian areas where immediate erosion control is needed while also creating hospitable conditions for plant establishment.

Coir rolls are generally placed offshore to break waves or applied at the toe of streambanks as a type of soft armor. Coir rolls provide a substrate for plant growth and facilitate sedimentation behind the roll by capturing sediment, mineral and organic materials.

Design Considerations:

Bioengineering techniques utilizing coir rolls and mats and vegetation should be considered as an alternative to stone revetments or other structural measures. Bioengineering techniques address aesthetic and ecological concerns by encouraging vegetation and wildlife habitat. Bioengineering techniques rely on plants and structures to function together in mutually reinforcing and complementary rolls. With coir rolls and coir mats, the high tensile strength coconut fibers, fiber netting and the wooden stakes used to anchor the material all comprise the structural components of the system.

Coir rolls, coir netting and coir mats also have high moisture retention properties and will generally last from four (4) to 12 years. However, coir fiber's strength, longevity and ability to hold moisture depend on the type, density and grade of coir material chosen.

Traditional processing of coconut fibers result in several different grades of coir. During processing, the initially separated fiber is called mattress fiber coir which is very short, thin and flimsy. The next grade of coir separated from the husk is called omat fiber coir. Once the mattress and omat fiber coir are separated, the remaining coir is called bristle fiber coir. Bristle fiber coir is longer, thicker, heavier and stronger compared to other types.

Coir rolls are commonly available in 12 inch, 16 inch, and 20 inch diameters. The density of the coir logs and coir mats depends on the type of fibers used in construction and how tightly the fibers are compacted. Tensile strength, unit weight, open area, thickness and coir type are important properties to consider when woven coir blankets, coir netting or coir rolls are specified. For instance, high density coir rolls, nine (9) lbs/cu. ft., might be more appropriate for high wave or high stream energy situations when low density rolls, six (6) lbs./cu. ft, would be perfectly acceptable for wetland restoration. Use light density coir if plant establishment is the only goal. Use high density coir if protection from high wave or high stream energy, longevity and plant establishment are the project goals.

Construction Considerations:

- Work site disturbance should be minimized. Protect any existing plants, when possible, and avoid additional disturbance that can lead to erosion and sedimentation.

- Install additional erosion and sediment control measures such as temporary diversion dikes and silt fences, as needed, before beginning work on the streambanks.

- Coir rolls can be used in the stream as a sediment barrier, silt curtain and/or coffer dam to control sediment while work is being done in the water.

- Determine mean water elevation. Mark the mean water level on a stake driven into the substrate, one (1) or two (2) feet streambank. Installing the materials and plants at the correct elevation is the most important aspect to assure success of the installation.

- Determine, on site, where the installation will begin and end. Begin installation at the downstream end.

- Prepare the site for installation of coir roll and coir mats by removing any large rocks, obstructions or material that may prevent the coir from making direct and firm contact with the soil.

- Regrade slope as designed. Gradual slopes, less steep than 2H:1V are preferred. Topsoil should be saved, if possible, and replaced once the subsoil has been removed or regraded. Soil shall be stored away from the water's edge and it shall be moved to its final location and stabilized as quickly as possible.

- Coir rolls must be level, installed along a horizontal contour.

- Place coir rolls parallel to the streambank or shoreline. Install the coir roll such that two (2) inches of the roll extends above the mean water elevation.

- Adjacent rolls shall be laced together, end to end, tightly and securely.

- Select and use wooden stakes made from strong, durable wood species that does not have knots or flaws. The stakes shall be pointed at one end, not wedge shaped.

- Stakes for coir rolls shall be approximately 1.5 inch diameter unless otherwise specified. Stake length shall be specified on the plan, dependent upon the type of substrate on the site.

- For typical applications at the waters edge, coir rolls are held in place with a single row of stakes, one (1) foot on center. Stakes may be driven through the netting on the outer edge of the roll. It is very difficult to drive stakes through the high density rolls however, a stake can be driven with the help of a pilot hole through the low density coir rolls.

- Coir rolls shall be placed along the streambanks at a height sufficient to protect the shore from flows or waves. Additional coir rolls may be placed above the lower rolls, in a tile-like fashion, to protect the upper shore or streambank.

- For typical offshore application of coir rolls, drive stakes one (1) foot on center on both sides of the roll, in parallel rows. Lacing across the stakes is used to hold the coir rolls in place. Weave lacing back and forth across the roll and attach the lacing to each stake, using knots, notches, staples, or nails.

- Coir mats, netting, and carpets shall be anchored by wooden stakes (typically one (1) inch x one (1) inch x two (2) foot long) driven through each corner and then staggered such that three (3) stakes are installed per square yard. Lacing among the stakes is recommended for coir mats exposed to extreme conditions such as ice, waves, or flooding.

- Plant materials, such as container grown pre-rooted plant plugs shall be planted into the coir rolls and through the coir mats and netting.

- When vegetating the coir rolls, small plant plugs shall be installed at a density of two (2) plugs per linear foot for a 12 inch diameter roll, three (3) plugs per linear foot for a 16 inch diameter roll and four (4) plugs per linear foot for a 20 inch diameter rolls.

- To install plant plugs into the coir roll, employ a planting iron or pilot bar into the roll and wedge it back and forth to create a hole for the plant. It is extremely important that the root system of the plant be placed below the water level. The plant plugs may be placed off to the side of the coir roll center line to assure the plant is low enough to contact water.

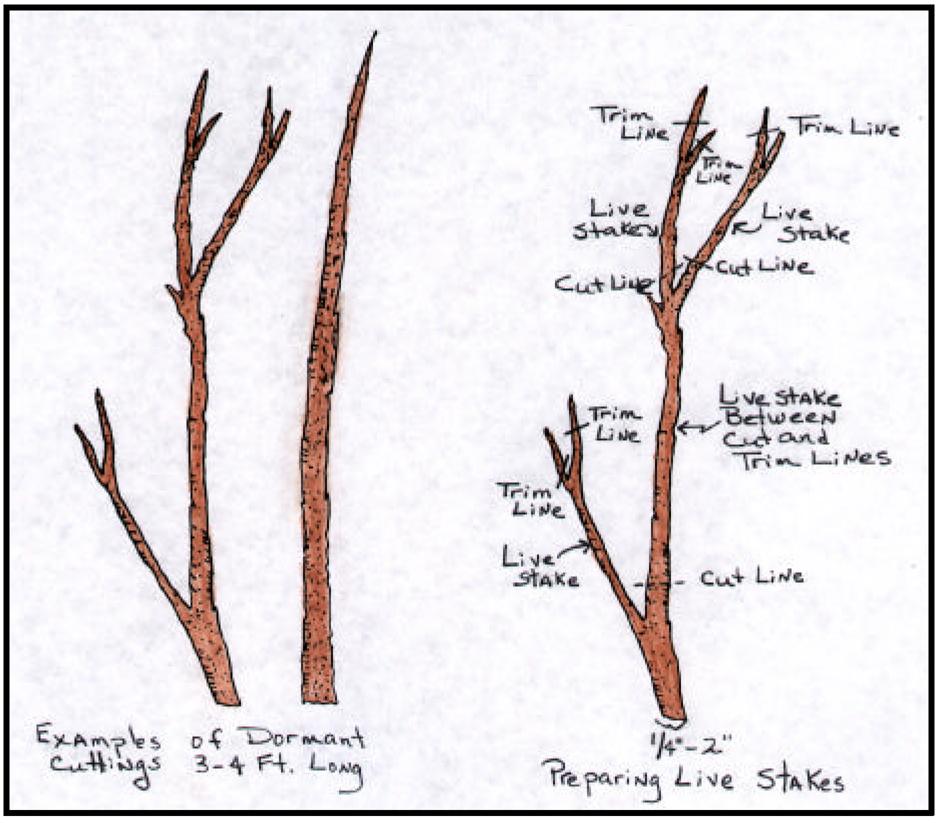
- The plant plug shall be installed firmly by covering the root ball and wrapping coir fiber around the stem.

- All plants shall be checked to ensure that they have been firmly installed in the substrate.

DORMANT POSTS OR DORMANT CUTTINGS.

(Information extracted from the USDA's Forest Service and Alaska Department of Fish and Game.)

Dormant post plantings or cuttings are harvested from living woody plants when the plants are not actively growing. See Figure 9. These post plantings or cuttings are collected from plants that can root easily without special treatment, such as cottonwood, willow, and poplar. They are embedded vertically into the lower slope of a streambank for development of vegetation cover which forms a permeable revetment, and restores some riparian functions. They also increase channel roughness, reduce flow velocities near the slope face and trap sediment in the treated area. They can also be used as live piling for toe stabilization where minor to moderate bank sloughing in occurring. They are useful for establishing riparian vegetation in arid regions where water tables are deep.



Dormant Cuttings **Figure 9**
adapted from State of Alaska

This technique is used along banks where erosion can be reduced by decreasing the near-bank velocities, and where vegetation can be established for providing other stream corridor functions. Posts or cuttings perform well in small, non-gravelly streams where ice damage is not a problem. They are generally self-repairing and will re-stem if attacked by beaver or livestock. However, provision should be made to exclude such herbivores where possible. Posts are less likely to be damaged by beavers and are subject less often to washouts than live stakes or smaller cuttings. They are preferred in arid regions or dry sites where water tables are too deep for smaller materials.

Avoid sites which are subject to abrasion from ice flows. Provide safeguards, against possible damage from rodents and other pests. Use only posts under 4-1/2 inches diameter to avoid diseases such as crown rot. Dormant posts generally have a higher mortality rate than other types of cuttings.

Select plant species appropriate to the site conditions. Willows and poplars have demonstrated high success rates. Unlike smaller cuttings, post harvesting can be very destructive to the donor stand. Therefore, they should be gathered as "salvage" from sites designated for clearing, or thinned from dense stands.

Plan the project harvesting and planting schedules. Appropriate windows may be as brief as two weeks, particularly in arid areas. Harvest and plant posts before bud break in spring.

Posts are cut from dormant trees three (3) to 4-1/2 inches in diameter and six (6) to eight (8) feet long or longer as needed for the site. In more arid areas it will be necessary to determine the depth to stable groundwater in considering harvest length.

The top surface should be sealed with paraffin or, in dry climates, a diluted latex paint. The posts should not be allowed to dry out during either transportation or storage. They should be kept covered, moist and cool. Saturation for two (2) hours prior to planting is recommended.

The posts are set in holes two (2) to four (4) feet on center in a square or triangular configuration, to a minimum of three (3) to four (4) feet deep (deeper as needed to access stable groundwater), formed by auguring, water jetting, or other techniques.

The streambank slope should be 2H:1V or flatter. The posts should be set deep enough to penetrate the permanent water table at least one (1) foot. Provide a minimum of one (1) foot of soil material around the post above the water table. From 1/2 to 2/3 of the post should be below ground. Place the posts with basal end down. It may be necessary to taper the basal end for easier insertion.

Supplement the system with appropriate soil bioengineering systems which may include rooted plants.

EROSION CONTROL BLANKETS/TURF.

(Information extracted from the USACE Waterways Experiment Station.)

Erosion control blankets are used to temporarily stabilize and protect disturbed soil from raindrop impact and surface erosion, to increase infiltration, decrease compaction and soil crusting, and to conserve soil moisture. Mulching with erosion control blankets will increase the germination rates for grasses and legumes and promote vegetation establishment. Erosion control blankets also protect seeds from predators, reduce desiccation and evaporation by insulating the soil and seed environment.

Some types of erosion control blankets and turf reinforcement mats are specifically designed to stabilize channelized flow areas. These blankets and mats can aide the establishment of vegetation in waterways and increase the maximum permissible velocity of the given channel by reinforcing the soil and vegetation to resist the forces of erosion during runoff events. Stems, roots, and rhizomes of the vegetation become intertwined with the mat, reinforcing the vegetation and anchoring the mat.

Erosion control blankets are typically made from straw, coconut fiber, excelsior or synthetic material that is enveloped in plastic or biodegradable netting. Erosion control blankets are generally a machine produced mat of organic, biodegradable mulch such as straw, curled wood fiber (excelsior), coconut fiber or a combination. These materials are evenly distributed on or between photodegradable polypropolyene or biodegradable natural fiber netting. Synthetic erosion control blankets are a machine produced mat of ultraviolet stabilized synthetic fibers and filaments. The nettings and mulch material are stitched to ensure integrity and the blankets are provided in rolls for ease of handling and installation.

Soil stabilization and turf reinforcement mats are high strength, flexible, machine produced, three-dimensional matrices of nylon, polyethylene, polypropolyene or polyvinyl chloride. They have ultra violet (UV) stabilizers added to the compounds to ensure endurance and provide “permanent vegetation stabilization.”

Erosion control blankets are suited for post-construction site stabilization, but may be used for temporary stabilization of highly erosive soils. They are suitable for steep slopes, stream banks and where vegetation will be slow to establish. Blankets and mats may be used for channels where water velocities over six (6) ft/sec are likely to wash out new vegetation. Erosion control blankets made of excelsior, coconut, or straw must be stapled to the surface especially in waterways and on steep slopes.

Installation:

- Prepare site prior to blanket installation. Grade and slope to the approved design and complete any runoff control such as diversions, berms or dikes prior to blanket installation.
- Fertilize and seed in accordance with seeding specifications prior to blanket installation. The seed bed should be free of rocks, clods or roots.
- Make sure all blankets are in uniform contact with soil.
- Make sure all lap joints are secure and staples are flush with the ground. Follow manufacturer's recommendations for securing and stapling blankets.
- Plant vines, ground covers, shrubs and other erosion control plants after installation.

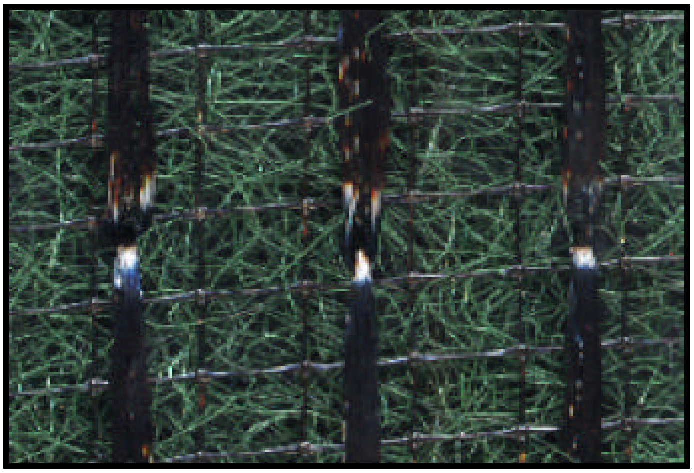
This method is being used today in many applications where previously a structural lining or armoring would have been required. Care must be taken to choose the type of blanket or matting which is most appropriate for the specific needs of a project. There are many soil stabilization products available today. It is very difficult to cover all the advantages, disadvantages and specifications of all the manufactured blankets and mats. Figures 10a and 10b illustrate several varieties of erosion control blankets.

Erosion Control Blankets
Figure 10a
Greenfix America & Belton Industries

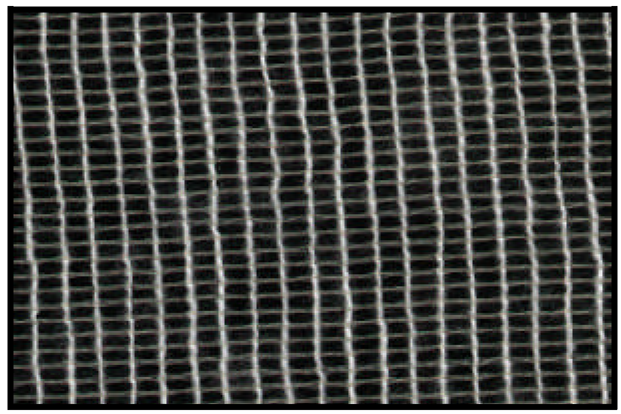
Erosion Control Blankets
Figure 10b
Erosion Control Systems & Bonterra® America

Figures 10a, 10b, and 10c displays just a few of the many assortments of erosion control blankets. The manufacturers listed provided samples of this type of technique. They start from top then left to right.

Erosion Control Blankets **Figure 10c**
North American Green, RoLanka International, Inc. & Belton Industries, Inc.



Turf Reinforcement Matrix
Figure 10d
Synthetic Industries



Turf Reinforcement Matrix
Figure 10e
Synthetic Industries

Turf Reinforcement Matrix
Figure 10f
Synthetic Industries

FABRIFORM® EROSION CONTROL SYSTEM.

(Information adapted from Construction Techniques, Inc. (CONTECH))

Fabriform® is a commercially developed product used for erosion control, flood protection, underwater construction, and many other uses. This process uses a double-layer fabric form woven especially for optimum strength, stability, adhesion and filtering characteristics. A highly fluid sand/cement slurry is pumped into this fabric envelope after it has been placed on the area to be protected.

Some Corps of Engineers applications of the product include:

- Waterway Bank Protection
- Shoreline Protection
- Reservoir Shoreline Protection (See Figure 11)
- Channel Stabilization (See Figure 12)
- Check Dam
- Levee and Abutment Protection
- Groins
- Breakwaters

Fabriform® Unimat Revetment **Figure 11**
Photo courtesy of CONTECH

Fabriform® Channel Stabilization **Figure 12**
Photo courtesy of CONTECH

GABIONS AND GABION (RENO) MATTRESSES.

(Information obtained from the EPA's Office of Wetlands, Oceans and Watersheds, the USACE Waterways Experiment Station, and extracted from Maccaferri Gabions, Inc., and "Erosion Draw.")

Gabions. Gabions are wire-mesh, rectangular baskets which are filled with small to medium size rock. The baskets are laced together to form a structural toe or sidewall. They are used for protecting steep slopes where scouring or undercutting is occurring or there are unusually heavy loading conditions. Gabions can be a cost-effective solution where some form of structural solution is needed and other materials are not readily available or must be brought in from distant sources. Plantings can be made between the gabions.

Gabions can be used where native rock is available, but is too small to meet stability requirements for structural toe protection or slope integrity. Gabions can also be used to form a steeper, stable side slope than can be achieved with rock riprap materials. They are appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce the slope steepness. See Figure 13 to illustrate gabions.

Consider using gabions where channel side slopes must be steeper than appropriate for riprap or other material, or where channel toe protection is needed, but rock riprap of the desired size is not readily available.

For wall heights greater than one (1) basket, consult a professional engineer about base configurations, or strictly follow manufacturers' recommendations for the site conditions.

Gabion baskets are available in vinyl coated wire as well as galvanized steel to improve durability. Performance life is generally fifty years unless located in areas with high alkaline or acidic waters.

Gabions may not be appropriate in heavy bedload streams or those with severe ice action because of serious abrasion damage potential.

Sometimes gabions are used in the construction of revetments. In addition to the surface layer of gabions, successful revetment designs also include an underlying layer composed of either geotextile filter fabric and gravel or a crushed stone filter and bedding layer. This lower layer functions to redistribute hydrostatic uplift pressure caused by wave action in the foundation substrate. Precast cellular blocks, with openings to provide drainage and to allow vegetation to grow through the blocks, can be used in the construction of revetments to stabilize banks. Vegetation roots add additional strength to the bank. In situations where erosion can occur under the gabions, fabric filters can be used to prevent the erosion. Technical assistance should be obtained to properly match the filter and soil characteristics. Typically gabions are hand placed when mechanical access to the bank is limited or costs need to be minimized.

Rock-filled or vegetated rock gabions are applicable to streambank sections which are subject to excessive erosion due to increased flows or disturbance during construction. This practice is applicable where flow velocities exceed six ft/sec and where vegetated streambank protection alone is not sufficient.

Gabions can be used to construct deflectors or groins intended to divert flow away from eroding streambank sections. Gabions are also used to construct retaining walls and grade control structures.

Gabion containers are generally fabricated from a double-twist, hexagonal meshes of heavily zinc coated wire. Some gabions use welded wire.

The rectangular gabion is divided into cells with diaphragms of equal capacity. The compartments add strength and assure that the full material remains evenly distributed.

Advantages of gabions include flexibility, durability, strength, permeability and economy versus rigid structures. The growth of native plants is promoted as gabions collect sediment in the stone fill.

Gabion Mattresses. Also referred to as *Reno mattresses* or *revet mattresses,* these structures are not as thick as gabions, and usually have a thickness of 0.5, 0.75, or one (1) foot. Gabion mattresses are used to line channels, armor streambanks and slopes, and used with gabions for grade control structures (spillways or aprons).

Gabion mattresses are often preferable to rock riprap alone. For any given hydraulic condition, the gabion mattress revetment thickness is one-third of an equivalent riprap design. Figure 13 illustrate gabion mattresses.

Gabion mattresses are flexible and free draining thus allowing some soil settling. They can be used in unstable streambeds and streambanks. Gabion mattresses can provide an important component to a “bioengineering” solution for streambank or slope erosion because they allow the growth and establishment of natural vegetation.

Gabion mattresses as well as gabions come in various sizes. Choose the dimensions of the gabions or combination of gabions to meet the design requirement site conditions.

Gabions (left bank) and Gabion (Reno) Mattress (right bank) **Figure 13**
photo courtesy of "Maccaferri Gabions, Inc."

Site Considerations:

All of the general streambank stabilization considerations are to be followed. The following are specific considerations for gabion structures. Gabion walls are appropriate where:

- The vertical integrity of a soil bank needs a higher tensile strength to reduce sloughing of the streambank.
- There is moderate to excessive sub-surface water movements that may be creating erosion and may damage other types of non-permeable structures.
- An excessively steep stream bank must be stabilized and vegetative or extreme mechanical means of stabilization (i.e., pulling back bank) are not feasible due to site conditions.
- Fill must be disposed of along an eroding streambank (fill can be placed behind gabions to modify slope).
- A retaining or toe wall is needed to stabilize the slope.

- Rock riprap is an appropriate practice but the available or desired rock size (smaller) is not sufficient alone to resist the expected shear stress exerted on the revetment.

Types of Gabion Structures:

- **Gabion Wall** - a gabion wall is basically a gravity wall which relies on its own weight and frictional resistance to resist sliding and overturning from lateral earth pressure.
- **Vegetated Rock Gabions** - a rock-filled gabion earth-retaining structure which has live branches placed between each consecutive layer of rock-filled baskets. The live branches will take root inside the gabion and into the soil behind the structure. The vegetation will consolidate the structures and bind it to the slope.
- **Gabion Deflector** - deflector or groins project into the stream and divert flows away from eroding streambank sections.
- **Gabion Aprons** - rock filled gabions or gabions mattress used as outlet protection, energy dissipators or spillways. These semi-flexible gabions are designed to settle without fracture and adhere to the ground if scour occurs.
- **Grade Control** - drop structures or weirs. Gabion baskets and mattresses can be combined to construct checkdams or weirs.
- **Channel Lining** - gabion mattresses can be used to line channels. The lining thickness depends on many factors such as the type of rock, design flow velocity, sediment and bedload, and channel gradient.

Construction Considerations:

- Design and install gabions in accordance with manufacturers standards and specifications.
- Gabions shall be fabricated in such a manner that the sides, ends, lid and diaphragms can be assembled at the construction site into rectangular baskets of the sizes specified and shown on the construction drawings.
- Gabions shall be of single-unit construction; the base, lid, ends and sides shall be either woven into a single unit or one edge of these members connected to the base section of the gabion in such a manner that the strength and flexibility at the connecting point is at least equal to that of the mesh.
- Where the length of the gabion exceeds 1-1/2 times its horizontal width, the gabion shall be divided by diaphragms of the same mesh and gauge as the body of the gabion, into cells whose length does not exceed the horizontal width.
- Gabions and gabion mattresses are unfolded and assembled. Corners are first joined together and then the diaphragms are attached to the side panels.

- Each gabion shall be assembled by tying all untied edges with lacing wire or approved fasteners. The lacing wire shall be tightly looped around every other mesh opening along the seams in such a manner that single and double loops are alternated.
- The gabion or gabion mattress shall be securely keyed into the streambank or streambed to assure that flows do not erode the soils beneath or around it.
- Starting at the lowest point of the slope, excavate the loose material two (2) to three (3) feet below the ground elevation until a stable foundation is reached.
- Excavate the back of stable foundation slightly deeper than the front so the foundation tilts back into the slope.
- A line of empty gabion units shall be placed in the bottom of the excavation and the baskets are to be joined together along adjacent edges, both horizontally and vertically. The base of the empty gabions placed on top of a filled line of gabions shall be tightly wired to the latter at front and back.
- For gabions greater than 18 inches, connecting wires, wires tied to opposite faces of each gabion cell, shall be installed during filling operations.
- Gabions shall be filled to a depth of 12 inches and then two (2) connecting wires shall be tightly tied to opposite faces of each gabion cell at a height of 12 inches above the base. Gabions shall then be filled with a further depth of 12 inches and two (2) connecting wires shall be similarly tied at this level. Then gabions shall be filled to the top.
- Fill gabions with appropriately sized river rock or quarry stone or other approved infill material. Use of hard material with high specific gravity is recommended. The tops of the gabions are then closed along edges and diaphragms using lacing wire or approved fasteners. Keep voids and bulges in the gabions to a minimum in order to ensure proper alignment and a neat, compact, square appearance.
- The stone size to fill gabion shall be three (3) to five (5) inches for gabion mattresses and four (4) to eight (8) inches for gabions.

GRASS ROLLS.

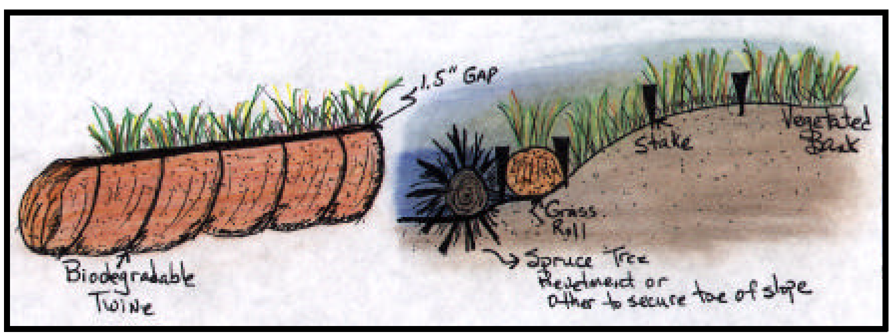
(Information obtained from the Alaska Department of Fish and Game.)

Grass rolls are often used to revegetate shorelines and streambanks where grasses and grass-like plants have been the primary vegetation type and where seeding is impractical due to fluctuating water levels or other factors. Clumps of grass sod are placed tightly together, side by side with shoots pointing up, in a sausage like structure and held together with burlap and twine. See Figure 14. The roll is then anchored in place. This technique reintroduces herbaceous vegetation to a site while simultaneously providing some structural stability. Ultimately the sod will form a dense root system along the streambank and provide structural protection to the site. When the grasses die back at the end of each growing season, their leaves hang over the streambank and provide rearing habitat for fish.

The grass roll is constructed by laying out a length of burlap and placing clumps of sod tightly together in the middle of the burlap. Use native grasses which produce a strong rhizome and a dense sod characteristic. Wrap the sides of the burlap over the sod clumps to make a sausage-like roll. Tie the roll every few inches with twine. Cut holes in the burlap wrap to expose the sod shoots. Try to create the grass roll onsite so that the length of the roll or rolls match the length of the area being planted.

The sod roll is installed in a shallow trench along the ordinary high water line after the toe of the slope has been protected. Anchor the grass roll securely into the bank. Earth anchors will be required for installations along streams and rivers. Stakes may be adequate for anchoring a grass roll in low-energy environments such as protected lakeshores. Revegetate the slope uphill from the sod roll.

The upstream and downstream ends of the grass roll need to be tied into a stable streambank, undisturbed vegetation, or other revegetation technique. The top of the grass roll should be fertilized with five (5) pounds of 8-32-16 fertilizer per thousand square feet of surface area. A slow release fertilizer may work very well for this application. Grasses are particularly sensitive to foot traffic and will not survive if they are not protected by elevated walkways or planted in areas with restricted access.



Grass Rolls **Figure 14**

adapted from the State of Alaska

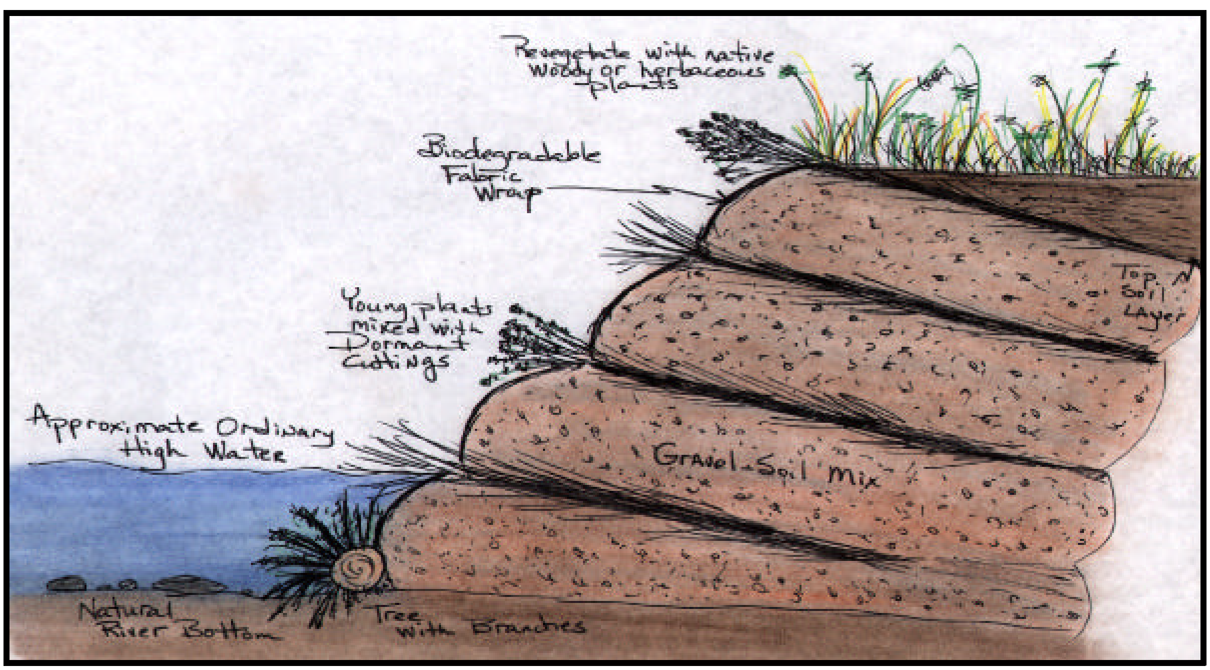
HEDGE - BRUSH LAYERING.

(Information extracted from the Alaska Department of Fish and Game.)

Hedge - brush layering is a revegetation technique that combines layers of plant material, both dormant cuttings and rooted plants, with soil to revegetate and stabilize a streambank. Greater plant diversity can be provided with a hedge - brush layer than with a simple brush layer. Rooted plants of species that do not root easily, such as alder, scouler and bebb willow, can be included in the plant layer. A mixture of species will more closely mimic undisturbed vegetation. Figure 15 illustrates this technique.

Select plant species suitable for site conditions. For the best results, dig transplants in spring or late summer and plant them the same day. If possible, root prune the plants several weeks prior to transplanting. Select plants that are less than five (5) to six (6) feet tall and root prune by inserting the shovel into the soil around the drip line. Skip every other shovel width. After the plant has been dug for transplanting, trim branches to compensate for root loss.

Before installation, choose a technique to secure the toe of the slope. Begin layering at the bottom of the slope. Along a stream, the first hedge - brush layer typically occurs at the ordinary high water level. Brush layers may be installed below the ordinary high water level to provide cover and fish habitat. These plants probably will not root and become established.



Hedge-Brush Layering **Figure 15**

adapted from the State of Alaska

Excavate the first bench two (2) to three (3) feet deep so that it angles slightly down and into the slope. Lay branches and transplants on the bench, slightly crisscrossing them. Place the cut ends of the branches and the roots of the transplants into the slope with the tips or shoots extending beyond the edge of the bench no more than 1/4 the total branch length. Plant 18-25 stems per yard. Fill the newly planted bench with two (2) to four (4) inches of soil and tamp into place. Continue building layers until the desired bank height is reached. The spacing between layers will vary with the erosion potential of the site. Sites with a shallow slope and low erosion potential can have wider spacing than sites with a steep slope and higher erosion potential. This technique can be easily mechanized, layer by layer, if it is installed during construction of a fill slope. On cut slopes and existing banks, each layer must be excavated. A hedge layer that is composed completely of transplants can be planted throughout the growing season from spring through early fall.

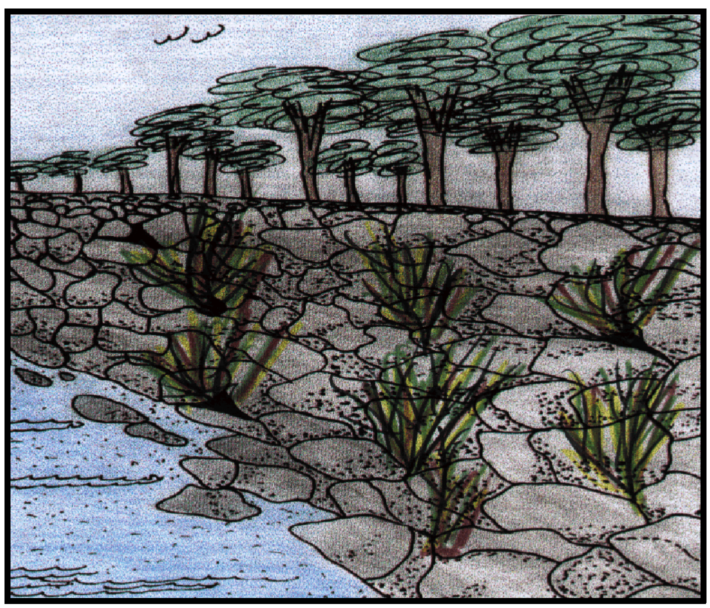
This technique is one of the best revegetation techniques for stabilizing slopes since the branches and transplants are placed directly into the slope which reinforces the soil. The transplants will add stability quickly as their roots become anchored. Relatively steep slopes can be stabilized with this technique if a biodegradable revegetation fabric is used to hold the soil in place between the plant layers. The front of the wrapped soil layer can be lightly seeded with grasses to increase soil stability while the woody plants become established. Overhanging branches provide shade.

JOINT PLANTING OR VEGETATIVE RIPRAP.

(Information extracted from the "Interagency Stream Corridor Restoration Handbook.")

Joint planting or vegetative riprap involves tamping of live stakes into joints or openings between rock pieces (riprap) which have previously been installed on a slope. This may be accomplished at the same time riprap is being installed on the slope. This method provides riparian habitat on sites where riprap is required or already exists. The root systems provide a mat which binds the soil base upon which the riprap rests and prevents loss of fines from this soil base. The root systems also improve the drainage of the soil base. Figure 16 illustrates this technique.

Joint plantings can be used wherever there is a lack of desired vegetative cover on the face of existing or required riprap slopes. This will provide stability to the soil base and provide vegetative cover for the sloped area. This method has few limitations and can be installed from base flow levels to the top of the slope. If plant material is not planted to reach ground water, then supplementary water may be required until the plant material is established. Very thick riprap layers (three (3) feet or thicker) may require special tools for establishing pilot holes.



Joint Planting or Vegetative Riprap Figure 16

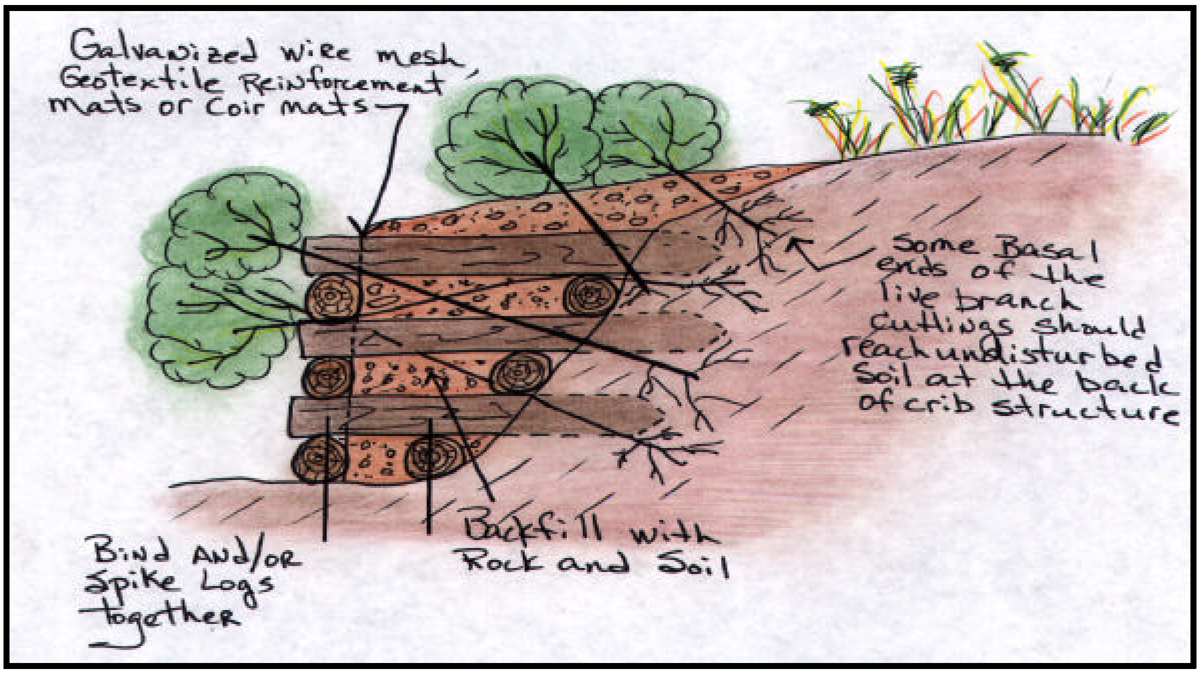
The live stake materials should be prepared in the standard manner. However, they should be 1.5 inches or larger in diameter and sufficiently long to penetrate well into the soil beneath the riprap layer. Native species should be used that root readily from cuttings. Plan cutting and planting when willows or other suitable species are dormant. Arrange to keep the cuttings moist and cool until planted.

Tamp the live stakes into the openings of the riprap during or after placement of the riprap. The basal ends of the stakes must extend into the backfill or undisturbed soil beneath the riprap. Do not drive with an ax or maul. If the soil is not easily penetrated, use a steel rod or a probe to prepare pilot holes for the stakes. Tamp to firm the soil so that the stake cannot be moved or readily pulled out. Install the live stakes perpendicular to the slope with the growing tips protruding slightly from the finished surface of the riprap. Place the stakes in a random configuration.

LIVE CRIBWALLS.

(Information obtained from the EPA's Office of Wetlands, Oceans and Watersheds and extracted from the "Interagency Stream Corridor Restoration Handbook.")

A live cribwall consists of a hollow, box-like interlocking arrangement of untreated log or timber members filled above base flow. The structure is filled with suitable backfill material and alternative layers of live branch cuttings, which root inside the crib structure and extend into the slope. Figure 17 illustrates this technique. Once the live cuttings root and become established, the subsequent vegetation gradually takes over the structural functions of the wood members.



Live Cribwall or Typical Log Cribbing **Figure 17**
adapted from "Erosion Draw"

Live cribwalls provide protection to the streambank in areas with near vertical banks where bank sloping options are limited. They afford a natural appearance, immediate protection and accelerate the establishment of woody species. They are useful in locations where the streambank slope is steep and there is sufficient space to provide a more horizontal type of treatment (such as riprap, brushpacking and brush mattresses); on outside of bends where high velocities are present; where there is a need to provide a natural streambank appearance; and where there is a need for immediate protection before vegetation can be established.

The application of live cribwalls should be kept to heights under seven (7) feet and should not exceed over 20 feet in length. This method is not appropriate where rock ballast and logs are not readily available and must be applied while branch cuttings are in dormancy.

The availability of logs, branches and rock and soil materials need to be determined. The logs should be from four (4) to six (6) inches in diameter. The lengths will vary with the size of the crib structure. Live branches should be from 0.5 to 2.5 inches in diameter and long enough to reach the back of the wooden crib structure.

Develop a typical cross section of the impaired streambank. Establish the configuration of the log crib on the cross section. Determine the likely depth of scour and establish that elevation as the base for the cribwall. Analyze the wall's dimensions to determine if they are appropriate for the site.

Excavate into the streambed to the depth of likely scour and to a width of the desired cribwall, generally five (5) to six (6) feet. Excavate the streambank side six (6) to 12 inches deeper than the front to ensure that the crib wall will be slightly tipped toward the bank.

Place the first course of logs at the front and back of the foundation from four (4) to five (5) feet apart and parallel to the slope contour. Add the next course at right angles to the bank face with three (3) to six (6) inches of overhang to the first course. Secure with nails, pins or reinforcing bars. Subsequent placement of courses will occur in the same sequence.

Place rock fill in the structure up to the height of the base flow surface. Rock on the outside of the cribwall may also be appropriate to this level.

Place the first layer of the cuttings at the baseflow water level. Add soil material which can support plant growth as the next layer. Ensure that the basal ends of the cuttings make contact with the undisturbed soil at the rear of the cribwall. Orient the tips of the branches to protrude slightly beyond the outside face of the cribwall. Continue placement of alternate layers in a like manner to the top elevation of the cribwall ending with a soil layer. Grade to join existing streambank surface and vegetate appropriately.

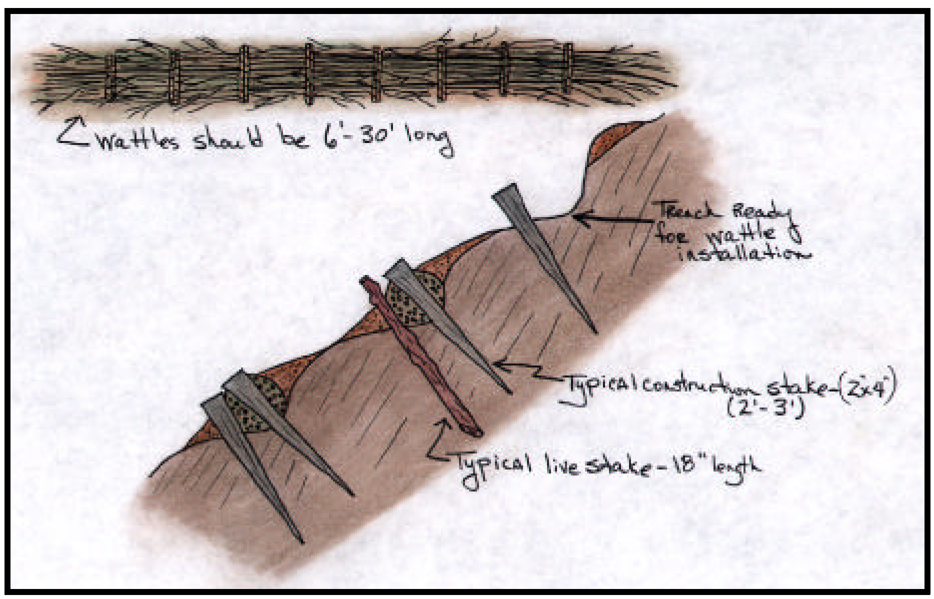
LIVE FASCINES OR WATTLINGS.

(Information extracted from "Erosion Control" , and obtained from the USACE's Waterways Experiment Station and the EPA's Office of Wetlands, Oceans and Watersheds.)

Live fascines (or wattles) are long bundles of dormant branch cuttings bound together into sausage-like, cylindrical structures. This method provides an effective stabilization technique for streambanks while requiring only a minimum amount of site disturbance. Figure 18 illustrates this technique.

Use live fascines/wattlings typically above the bankfull discharge level except on very small discharge sites. Use them to protect the streambank from shallow slides (one (1) to two (2) feet depth), to provide immediate protection from surface erosion, to trap and hold soil, to facilitate drainage, and to enhance conditions for colonization of native vegetation. Live fascines/wattlings integrate well with other treatments as well, such as structural toe protection and brush mattresses.

Live fascines/wattlings are not appropriate for treatment of slopes undergoing mass movement or at locations below bankfull discharge levels.



Live Fascines or Wattlings **Figure 18**
adapted from "Erosion Draw"

Cuttings must be from species, such as young willows (or Cornus, Baccharis, Populus), that root easily and have long, straight branches. The best planting times are in late autumn at the onset of plant dormancy or in early spring before growth begins. Willows have several different growth forms, from shrubs to large trees. Small to medium sized shrub-type and rhizomatous or creeping-type willows are used for planting channel banks. Upland willow species are found in relatively dry areas and should be used on similar sites. Tree-type willows are selected for the upper bank and flood plain area.

Planting method using the live fascine/wattling alternative include the following advantages:

- Energy dissipation;
- Temporary stabilization to allow establishment of other vegetation; and
- Sediment entrapment, which can become a part of the vegetation component.

If using live fascines/wattlings on steep cuts and fills and project areas that are subject to downhill movement, they must be placed on contour. When subject to wave action, they should be placed diagonally to the wave action.

Live fascine/wattling preparation and planting specifications are as follows:

- Live fascine/wattling bundles shall be prepared from live, shrubby material, preferably of species which will root, such as Coyote Willow (*Salix exigua*), Laurel Willow *(Salix pentanda)*, Prairie Willow *(Salix humilis)*, 'Siouxland' Eastern Cottonwood *(Populus deltoides)*, 'Imperial' Carolina Poplar *(Populus canadensis)*, and Robust Popular *(Populus robusta)*.
- Choose plant materials that are adapted to the site conditions from species that root easily. A portion (up to 50 percent) of the bundle may be of material that does not root easily or dead material.
- Cuttings should be harvested and planted when the willows, or other chosen species, are dormant. This period is generally from late fall to early spring.
- Live fascine/wattling bundles may vary in length, depending on material available. Bundles shall taper at the ends and shall be approximately five (5) to 10 feet or more, depending on site conditions and limitations in handling. Butts shall not be more than plus or minus 1-1/2 inches in diameter.
- Stems shall be placed alternatively (randomly) in each bundle so that approximately one-half the butt ends are at each end of the bundle.
- When compressed firmly and tied, each bundle shall be eight (8) inches in diameter.
- Bundles shall be tied on 12 to 15 inch centers with two (2) wraps of binder twine or heavier tying material with a non-slippage knot. Be sure that the string or twine used for bundling is untreated twine or string. Polypropolene "tree rope" approximately 3/16 inch diameter provides the necessary strength and durability.
- Bundles shall be prepared not more than two (2) days in advance of placement except that if kept covered and wet, they may be prepared up to seven (7) days in advance of placement.
- Prepare live stakes and dead stout stakes at 2.5 feet in length.
- Prepare the live fascine/wattling bundles and live stakes immediately before installation.
- Work shall progress from the bottom to the top of the slope.

- Perform any slope repairs, such as gully repair, slope scaling, diversion dike, gabion, or toe wall construction, prior to wattle installation.
- Grade for the live fascine/wattling trenches shall be staked with an Abney level, or similar device, and shall follow slope contours (horizontally).
- Beginning at the bankfull level, dig a trench on the contour approximately 10 inches wide and deep.
- Spacing of contour trenches (live fascine/wattles) is determined by soil type, potential for erosion and slope steepness.
- Excavate trenches up the slope at intervals specified in Table 2. Where possible, place one (1) or two (2) rows over the top of slope. Place the live fascine/wattles immediately after trenching to reduce desiccation of the soil.

TABLE 2. GENERAL LIVE FASCINE/WATTLING INSTALLATION GUIDELINES

Slope Horizontal:Vertical (H:V)	Slope Distance Between Live Fascine/Wattles in Feet	Recommended Maximum Slope Length in Feet
1:1 to 1.5:1	3 - 4	15
1.5:1 to 2:1	4 - 5	20
2:1 to 2.5:1	5 - 6	30
2.5:1 to 4:1	6 - 8	40
3.5:1 to 4:1	8 - 12	50
4.5:1 to 5:1	10 - 20	60

- Bundles shall be laid in trenches dug to approximately one-half the diameter of the bundles, with ends of bundles overlapping at least 12 inches. The overlap shall be as long as necessary to permit staking.
- Bundles shall be staked firmly in place with vertical stakes on the downhill side of the wattling, not more than 18 inches on center and diagonal stakes through the bundles of not more than 30 inches on center. Where bundle overlap occurs between previously set bottom or guide stakes, an additional bottom stake shall be used at the midpoint of the overlap. Bundle overlaps shall be “tied” with a diagonal stake through the ends of both bundles.
- Stakes may be made of live wattling material greater than 1-1/2 inches in diameter or they may be construction stakes (2" x 4" x 24" or 2" x 4" x 36" diagonal cut.) Reinforcing bar may be substituted (see next bullet.)

- All stakes shall be driven to a firm hold and a minimum of 18 inches deep. Where soils are soft and 24 inch stakes are not solid (i.e., they can be moved by hand), 36 inch stakes shall be used. Where soils are so compacted that 24 inch stakes cannot be driven 18 inches deep, 3/8 to 1/2 inch steel reinforcing bar shall be used for staking.
- Work shall progress from the bottom or the cut or fill toward the top. Each row shall be covered with soil and packed firmly behind and on the uphill side of the live fascine/wattling by tamping or by walking on the live fascine/wattling as the work progresses or by a combination of these methods.
- The downhill "lip" of the live fascine/wattling bundle shall be left exposed when staking and covering are completed. However, the preceding specification must be rigorously followed.
- Use appropriate techniques to establish vegetation between rows (e.g. live stakes, brush mattresses) or use weed with mulch, jute mesh, coconut netting or other acceptable erosion control fabric. Shallow slopes, generally 3H:1V or flatter may be seeded and mulched by hand. Steeper slopes should have seed applied hydraulically and the mulch shall be anchored with tackifier or other approved methods.
- Place moist soil along the sides of the bundles. The tops of the live fascine/wattlings should be slightly visible when the installation is completed.

LIVE SILTATION.

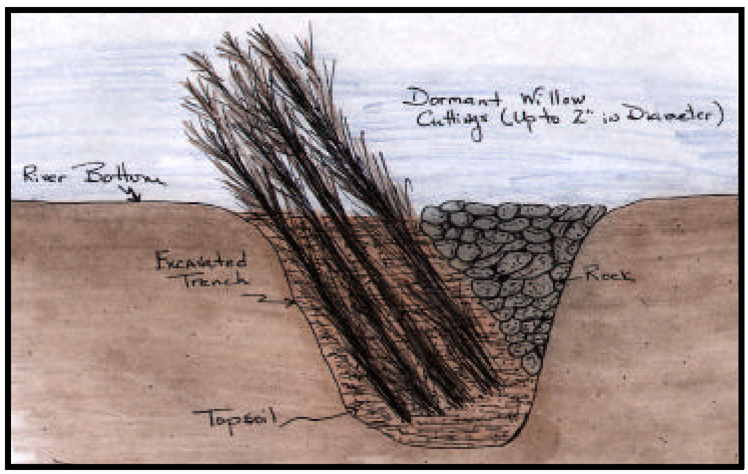
(Information obtained from the Alaska Department of Fish and Game.)

Live siltation is a revegetation technique used to secure the toe of a slope, trap sediments and create fish rearing habitat. The system can be constructed as a living or a non-living brushy system at the water's edge. Figure 19 illustrates this technique.

The dormant branches need to be a minimum of three (3) feet long with side branches still attached. If a living system is planned, Feltleaf or Pacific willow is recommended. Any woody plant material such as alder, can be installed for a nonliving system.

This system is installed by constructing a V-shaped trench at the ordinary high water line with equipment or hand tools. Excavate a trench so that it parallels the toe of the streambank and is approximately two (2) feet deep. Lay a thick layer of willow branches in the trench so that one-third of the length of the branches are angling out towards the stream. Place a minimum of 40 willow branches per yard in the trench.

Backfill over the branches with a gravel soil mix and secure the top surface with large washed gravel, bundles (fascines), or coir logs. Both the upstream and downstream ends of the live siltation construction need to be securely tied into a stable streambank to reduce the potential for the system to wash out. More than one (1) row of live siltation can be installed. A living and growing siltation system typically is installed at ordinary high water line.



Live Siltation **Figure 19**

adapted from State of Alaska

A nonliving system can be constructed below the ordinary high water line during low water levels. If it is impossible to dig a trench, the branches can be secured in place with logs, armor rock, bundles (fascines) or coir logs.

This technique is particularly valuable for providing immediate cover and fish rearing habitat while other revegetation plantings become established.

LIVE STAKING.

(Information extracted from "Erosion Draw", and obtained from the EPA's Office of Wetlands, Oceans and Watersheds, and Alaska Department of Fish and Game,)

Live staking is an effective streambank protection technique where site conditions are uncomplicated, construction time is limited, and an inexpensive method is needed. It is an appropriate technique for repair of small earth slips and slumps that are frequently wet. Live stakes can be used to peg down surface erosion control materials. They stabilize intervening areas between other soil bioengineering techniques, and they produce streamside habitat.

Live stakes are live, woody cuttings which are inserted and tamped into the soil. If correctly handled, prepared, and placed, the live stake will root and grow. A system of live stakes are used to create a living root mat that stabilizes the soil by reinforcing and binding soil particles together, and by extracting excess soil moisture. Dense root masses also can prevent erosive forces from dislodging and moving soil particles. Most willow species are ideal for live staking, because they root rapidly and begin to dry out a slope soon after installation.

Note: Do not use live stakes by themselves on complex sites. Integrate with other techniques (i.e., anchor blankets, coir mats, turf reinforcement mats, straw rolls, etc.).

The following, lists conditions where this practice applies:

- Repair of small earth slips and slumps.
- Gullies and stream channels can be live-staked. Areas best suited to staking are the bottoms and banks of small developing gullies, sediment fills behind check dams and bare gully banks.
- Live stakes can be inserted or driven through interstices or openings in gabions, riprap, articulated block, or cellular confinement systems.
- Live willow stakes can be used to anchor and enhance the effectiveness of willow wattles, straw rolls, coir rolls, turf reinforcement mats, coir mats, continuous berms and other erosion control materials.
- As a temporary measure, live willow staking performs an important function of stabilizing and modifying the soil, serving as a pioneer species until other plants become established.
- Several species of willow will grow from cuttings in less favorable soil conditions such as road fills and gullies in bare denuded land. Even in very unfavorable sites, willow cuttings will often grow vigorously for a few years before they die out.

The following, lists the planning considerations:

- Live stake harvest and installation should be performed during its dormant season, late fall to early spring.
- Use site reconnaissance to identify willow species, growth form, soil and site conditions on adjacent sites and compare their conditions to the construction site. Planting will be more successful as soil, site and species selected match stable, vegetated nearby sites.
- If native willows or cottonwood are not found in the vicinity, live staking may not be a good option.
- Choose plant material adapted to the site conditions and confirm the availability of plant material that will be used on site before construction begins.

Willows have several different growth forms, from shrubs to large trees. Small to medium sized shrub-type and rhizomatous or creeping-type willows are used for planting channel banks. Upland willow species are found in relatively dry areas and should be used on similar sites. Tree-type willows are selected for the upper bank and flood plain area.

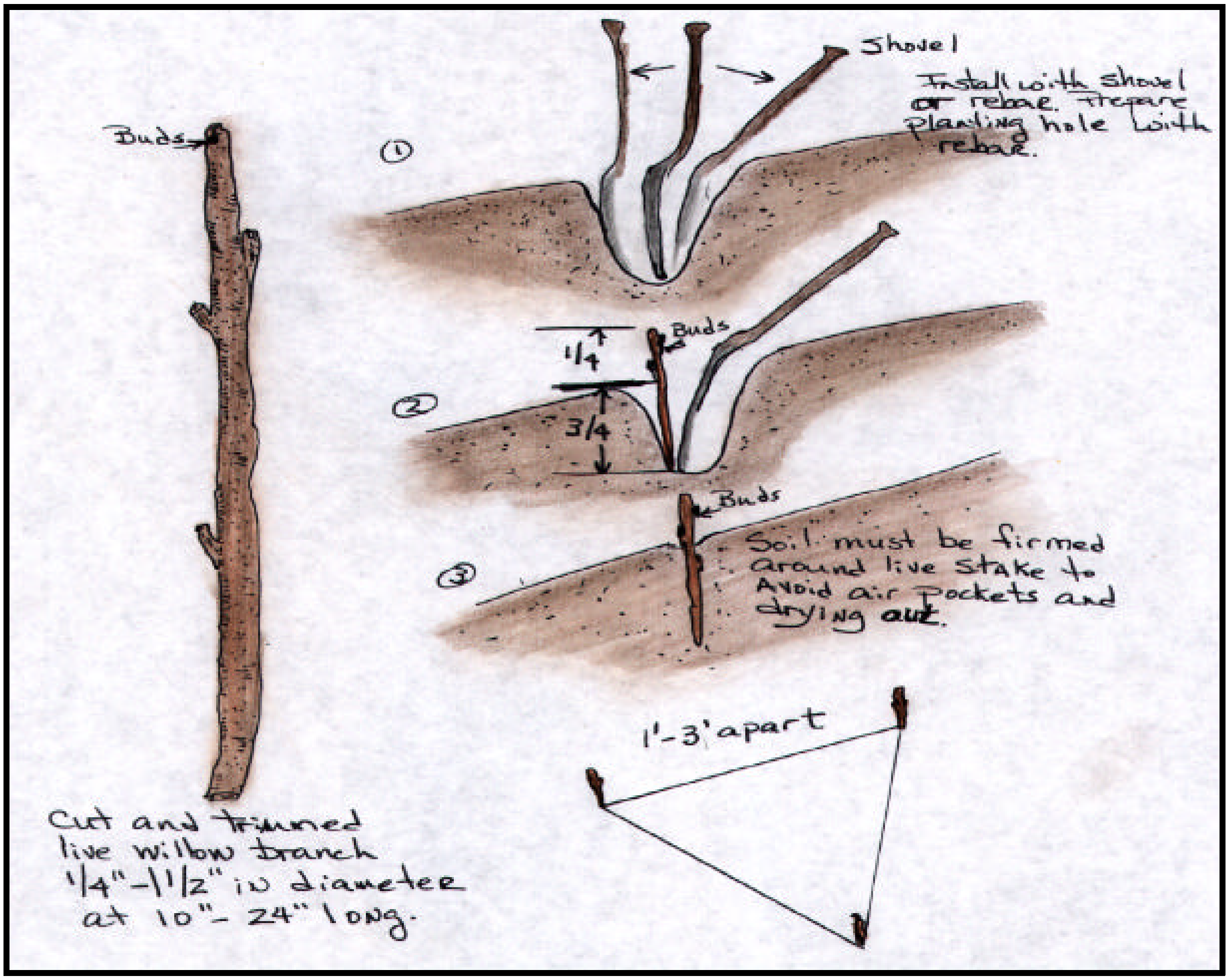
The following, lists the construction considerations:

Harvesting:

- Stakes shall be harvested and planted when the willows, or other chosen species, are dormant. This period is generally from late fall to early spring, or before the buds start to break.
- When harvesting cuttings, select healthy, live wood that is reasonably straight.
- Use live wood at least one (1) year old or older. Avoid suckers or current years growth as they lack sufficient stored energy reserves to sprout consistently. The best wood is two (2) to five (5) years old with smooth bark that is not deeply furrowed.
- Make clean cuts with unsplit ends. Trim branches from cutting as close as possible. The butt end of the cutting shall be pointed or angled and the top end a square cut.
- Identification of the top and bottom of cuttings are accomplished by angle cutting the butt end. The top, square cut, can be painted and sealed by dipping the top one (1) to two (2) inches into a 50-50 mix of light colored latex paint and water. Sealing the top of stake will reduce the possibility of desiccation and disease caused mortality. Assure the stakes are planted with the top up, and make the stakes visible for subsequent planting evaluations.

Diameter:

- Cuttings should generally be 3/4 inch or larger depending on the species. Highest survival rates are obtained from using cuttings two (2) to three (3) inches in diameter. Larger diameter cuttings are needed for planting into rock riprap.



Live Staking **Figure 20**
adapted from the State of Alaska

Length:

- Cuttings of small diameters (up to 1-1/2 inches) shall be 18 inches long minimum. Thicker cuttings should be longer.
- Cuttings should be long enough to reach into the mid-summer water table, if possible.

- Stakes should be cut so that a terminal bud scar is within one (1) to four (4) inches of the top. At least two (2) buds and/or bud scars shall be above the ground after planting.

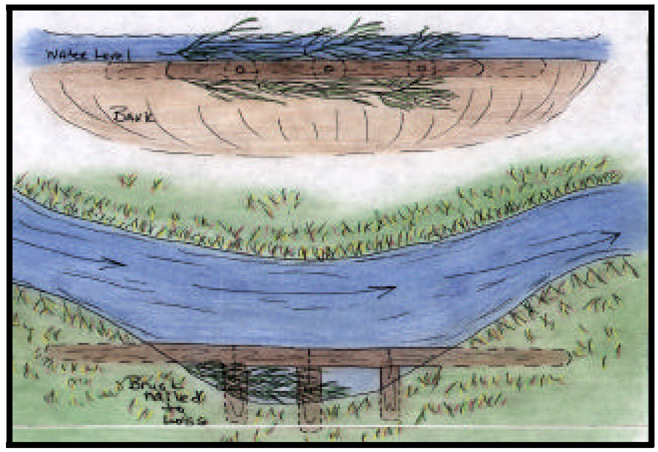
Installation: (See Figure 20).

- Stakes must not be allowed to dry out. All cuttings should be soaked in water for a minimum of 24 hours. Soaking significantly increases the survival rate of the cuttings.
- Place erosion control fabric or materials on slopes subject to erosive inundation.
- Stakes must be planted with butt-ends into the ground at right angles to the slope face. Leaf bud scars or emerging buds should always point up. Use only dead blow hammers (hammer head filled with shot or sand) if necessary to sink stakes.
- Plant stakes one (1) to three (3) feet apart.
- Set the stake as deep as possible into the soil, preferably with 80 percent of its length into the soil and in contact with mid-summer water table.
- Space the live stakes in a triangular configuration two (2) to three (3) feet apart. The overall density of the installation should be two (2) to four (4) stakes per square yard.
- It is essential to have good contact between the stake and soil for roots to sprout. Tamp the soil around the cutting.
- Use an iron stake or bar to make a pilot hole in firm soil.
- Do not damage the buds, strip the bark or split the stake during installation.
- Split or damaged stakes shall be removed and replaced.

LOG AND BRUSH SHELTER.
(Information obtained from the USDA's Forest Service.)

This device is designed to provide overhead cover. A certain degree of streambank protection is also provided, although less than with cribs. The brush and slash attached to the platforms also harbor aquatic and terrestrial insects eaten by fish.

The finished shelter is simply a rack or shelf projecting from the bank to which brush or coarse logging debris can be attached. Brace or abutment logs and the ends of the main log should be dug several feet (four (4) to 15 feet depending upon distance spanned and bank stability) into the bank and then pinned together with 5/8-inch rebar. The life of the structure will be much greater if all logs are submerged. Brush or debris should be attached so that portions are above and below the water surface. Figure 21 illustrates this technique.



Log and Brush Shelter **Figure 21**
adapted from the Forest Service

These structures are most suitable for use in low gradient stream bends where open pools are already present. Placement in conjunction with a deflector can enhance results.

Materials are inexpensive, and a comparatively large area of overhead cover is provided at each site. Brush provides maximum surface for both terrestrial and aquatic insects.

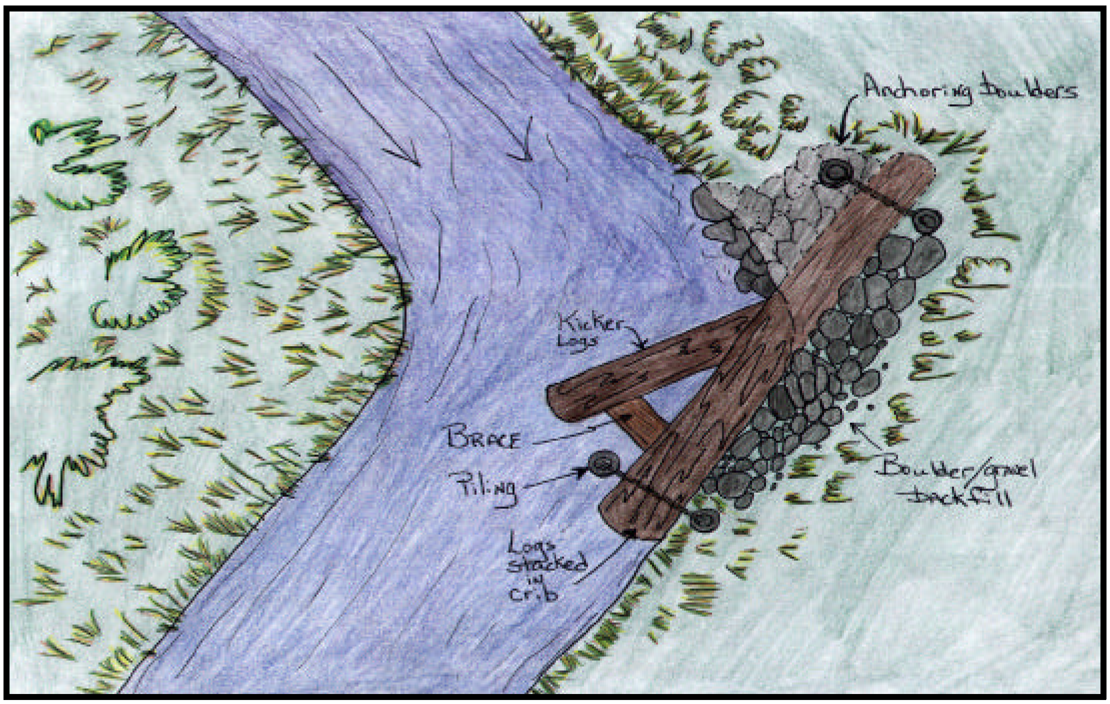
The opportunity for installing these structures is limited to relatively few situations. Extensive excavation is required if streambanks are high.

Output should range from two (2) structures per crew day on a small stream with low banks (two (2) to four (4) feet) to one (1) per day on larger streams with higher banks.

LOG CRIBBING.

(Information extracted from "Applied River Morphology.")

Log cribbing is a retaining structure built of logs to protect streambanks from erosion. Log cribbing is normally built on the outside of stream bends to protect the streambank from the impinging flow of the stream with log cribbing, live willow (or other riparian species) stakes can be planted between the logs, behind the structure and immediately adjacent to the cribbing. Figure 22 illustrates log cribbing.

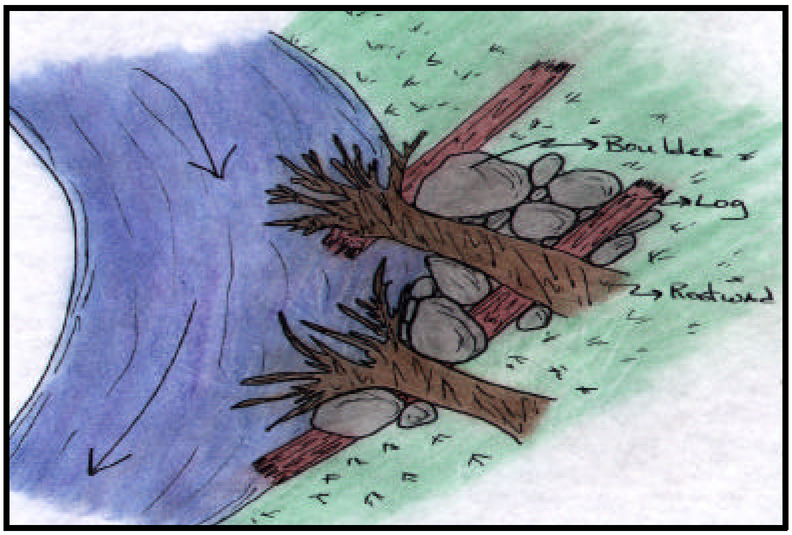


Log Crib Bank Protection **Figure 22**
adapted from "Applied River Morphology"

LOG, ROOTWAD AND BOULDER REVETMENT (NATIVE MATERIAL REVETMENT).
(Information extracted from "Applied River Morphology", and the USDA's "Streambank and Shoreline Protection - Chapter 16".)

These revetments are systems composed of logs, rootwads, and boulders selectively placed in and on streambanks. See Figure 23 for an illustration of this technique. Log, rootwad and boulder revetments provide effective streambank erosion control in higher velocity streams, as well as trap sediment between components, support restoration of slope vegetation, and distribute flow velocities and instream sediments for fishery use. It also provides a natural look, provide an abundance of cover, shading, detritus, terrestrial insect habitat, and diversity of habitats.

The site must be accessible to heavy equipment. Materials may not be native or readily available at some locations. This technique can be expensive, but compares well to other structural treatments and is generally superior for habitat function.



Log, Rootwad and Boulder Revetment **Figure 23**
adapted from "Applied River Morphology"

A cross section should be developed of the installed modifications. This cross section will show the expected depth of scour, baseflow level, bankfull level, location of the footer log (locate the bottom below expected scour depth), and rootwad and boulder positions. The associated vegetative plantings and soil bioengineering systems should also be shown. Also provide any anchoring details that may be required.

Provide a plan view, map or at least a sketch to show the location and spacing of rootwads and boulders and the horizontal extent of the system, and its context with surrounding features.

Select 16 inch or larger diameter logs that are crooked and have an irregular shape. Select rootwads with numerous protrusions and eight (8)- to 12-foot long boles. Select irregularly shaped boulders as large as possible, but at least one (1) and one-half times the log diameter. Integrate with soil bioengineering techniques on the upper slope.

Schedule installation for times which will least interfere with fishery and other instream functions.

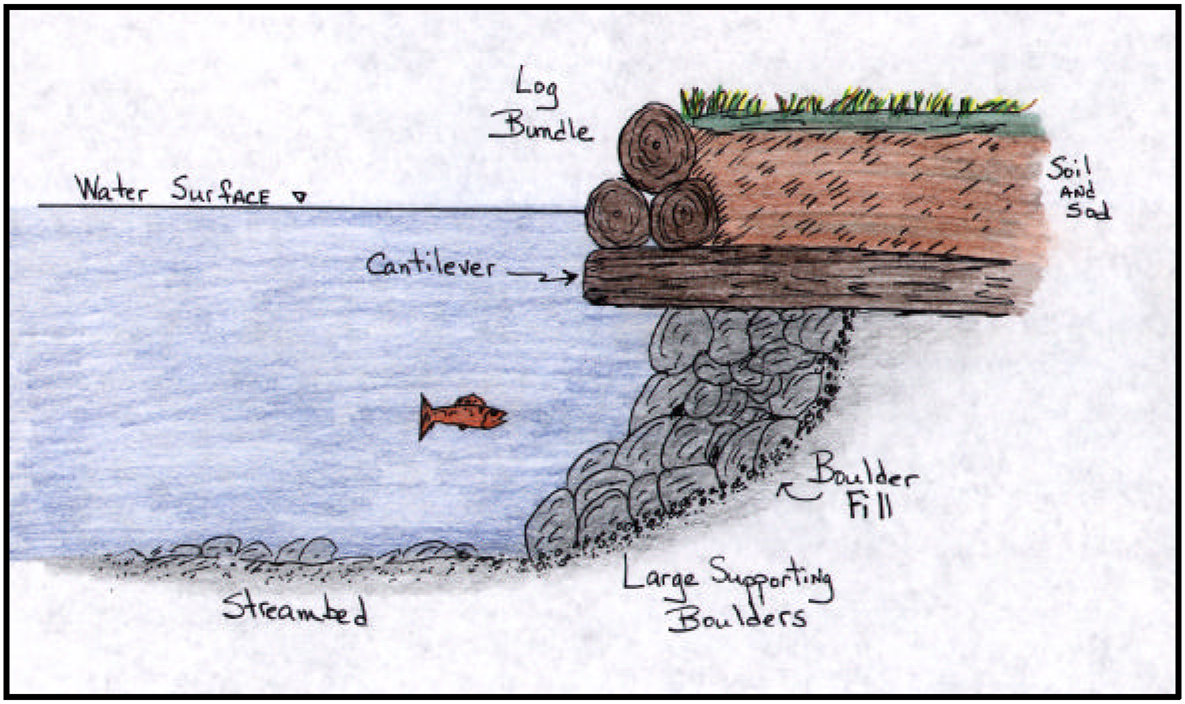
Prepare subgrade to be a depth below the streambed that will protect against anticipated scour (at least one (1) and one-half the footer log diameter.)

Install a footer log at the base and parallel to the streambank at its midsection. Use boulders to anchor the footer log against floatation. Excavate trenches into the bank to accommodate the rootwad boles (eight (8) to 12 feet). Orient the trenches to allow placement of the root mass in a way that faces slightly towards the direction of flow and to allow the brace roots to be flush with the streambank. Backfill and combine vegetative plantings and soil bioengineering systems behind and above the rootwads. These can include live stakes and dormant post plantings in the openings of the slope below bankfull stage. Place live stakes, fascines and other treatments above the revetment. If bankfill material will be subject to erosion flows, then treatment should be used to stabilize the banks above the revetment.

OVERHANGING BANK COVER.

(Information extracted from "Applied River Morphology".)

Overhanging bank covers are rearing habitat enhancement structures. They are installed to create an undercut bank effect, thus providing hiding cover for fish. They are built along the outside bends or along straight reaches in conjunction with deflectors so that they always have adequate water depth below. Figure 24 illustrates an overhanging bank cover.



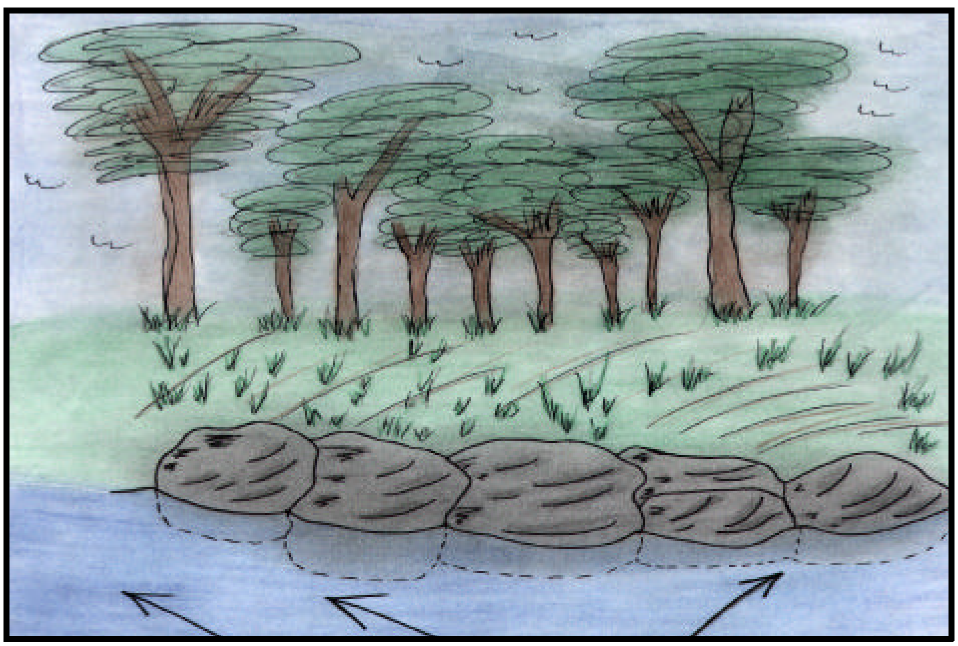
Overhanging Bank Cover **Figure 24**

adapted from "Applied River Morphology"

PLACEMENT of BOULDERS (BOULDER PLACEMENT).

(Information obtained from the USACE Walla Walla District and Waterways Experiment Station.)

Boulder placements are large boulders placed in critical places to protect banks and in midstream areas to provide fish resting areas. In most cases, this method would only slow the erosion process because boulders tend to settle into self-induced scour holes and disappear. Some success has been reported with groups sited carefully to avoid the main current and tied to high ground or other structures. In any case, the resting pools provided are similar in habitat quality to those provided by other means and would have a very natural appearance. Large boulders or riprap would provide relatively permanent structures and protect banks and islands from erosion for many years. Boulder placement is illustrated in Figure 25.

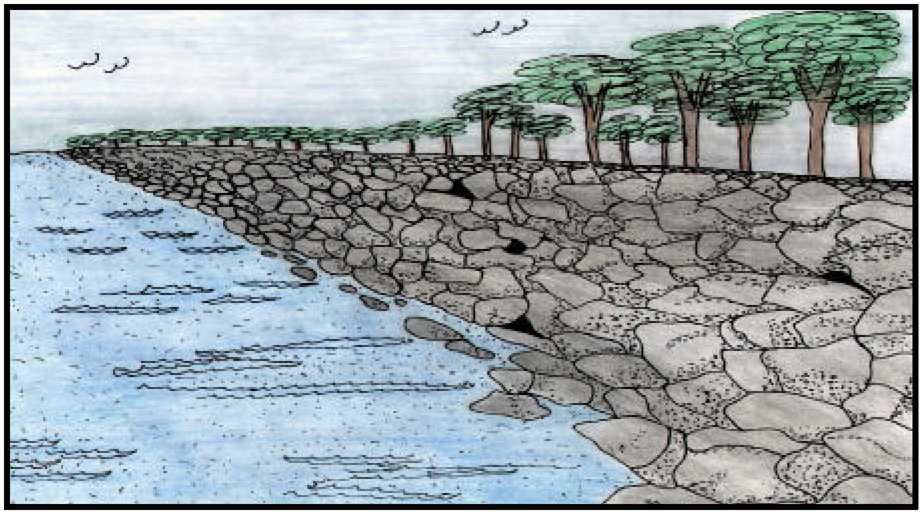


Boulder Placement **Figure 25**

adapted from Walla Walla USACE

RIPRAP.

(Information extracted from "Trout Stream Therapy," "Erosion Draw," and "Interagency Streambank Corridor Restoration Handbook.")



Riprap (Full Bank) **Figure 26**

Riprap is a layer of stone designed to protect and stabilize areas subject to erosion. Figures 26 and 26a illustrates a full bank riprap. This method of a revetment is usually implemented when shoreline, riverbanks and streambanks have such severe erosion that requires extensive protection. If properly designed and installed, it can last indefinitely where the streambank is exposed to high velocity conditions and the streambed are not expected to degrade. Riprap can easily be integrated as a component of other bank restoration systems.

When vegetation or biotechnical techniques are not practical, this method is normally used. If stone is available in sufficient size and quantity, this method can be constructed at a reasonable price. If the stone is not readily available, this method can get relatively expensive due to transportation costs. In these cases, other structural methods should be investigated.

Riprap (Full Bank) **Figure 26a**
Near Sequim, Wash.

When considering riprap for surface stabilization, it is important to anticipate visual impacts, including weed control, hazards from snakes and other animals, danger of slides and hazards to areas below steep riprap slopes, damage and possible slides from people moving stones, and general safety.

Use riprap alone where long term durability is needed, streamflow is swift, there is a significant threat to life or high value property and there is no practical way to incorporate vegetation into the design. Riprap can easily be integrated as a component of other bank restoration systems (such as stone toes without bank shaping, and stone toe with vegetation on the upper bank, See Figure 26b.)

Riprap at Toe of Streambank with Vegetation Figure 26b
Photo courtesy of Synthetic Industries

Investigate the streambank damage to determine the likely cause of failure. Structural toe protection will be appropriate if erosion is occurring at the base of the slope and cannot be prevented by plant growth because of permanent water in the toe area.

Riprap is classed as either graded or uniform. Graded riprap includes a wide mixture of stone sizes. Uniform riprap consists of stones nearly all the same size. Graded is preferred to uniform in most applications, because it forms a dense, flexible cover. Uniform is more open and cannot adjust as effectively to movement of the stones. Graded is less expensive to install requiring less hand work for installation than uniform, which must be placed in a uniform pattern. Uniform may provide a more pleasing appearance.

Riprap is expensive both in cost of materials and equipment usage. Rock color should match the existing channel materials for natural appearance. Suitable rock may not be available close by or in the required sizes. Supplies of rock should be free of toxic substances.

Materials needed for riprapping are stone or local cobbles, gravel, small rock, filter blanket, and/or woven filter cloth. The equipment needed are a grader, truck and a crane. Foundation material should be closely evaluated before any construction transpires as soft foundations could result in substantial settlement. Non-cohesive material should be protected by adequate filter material to prevent leaching or sloughing. Loose or soft foundations are subject to shifting or sliding and layered materials can lead to piping. Hydrostatic pressures within the bank can also lead to internal movement. A geotechnical evaluation is encouraged.

The study team needs to do the following before starting any riprap job:

- Obtain channel profile, cross section, horizontal geometry, and roughness data;
- Perform hydrologic and hydraulic analyses of the affected stream reach;
- Investigate the bank and streambed soil materials;
- Establish the acceptable risk for design;
- Determine the size distribution, thicknesses and height of riprap that will be needed including consideration for ice action as applicable;
- Develop one or more typical cross sections to show the rock riprap positioning;
- Filter details, heights, thickness, etc.;
- Provide a plan view sketch, aerial photo or drawing to indicate the alignment and horizontal features of the installation;
- Show tiebacks into the streambanks at both the upstream and downstream ends;
- Make sure of proper slope selection and surface preparation which are essential for successful long term functioning of riprap;
- Adequate compaction of fill areas and proper use of filter blankets or aggregate foundation is necessary;
- The bank should be graded and compacted to a slope of 2H:1V or flatter and the gravel, small rock, filter blanket and/ or woven filter cloth placed on the prepared slope. A larger or local cobble should be place carefully with a crane;
- Determine if an underlying filter material will be needed to protect against erosion of bank soil materials beneath the riprap. An engineering analysis will determine this need, but generally a filter may be needed if the soils lack cohesive strength or there are significant seepage pressures in the bank's soils.

A filter blanket is a layer of material placed between the riprap and the underlying soil to prevent soil movement, into or through, the riprap. A suitable filter may consist of a well-graded gravel or sand-gravel layer or a synthetic filter fabric manufactured for this purpose. The design of a gravel filter blanket is based on the ratio of particle size in the overlying filter material to that of the base material in accordance with the criteria below. The designed gravel filter blanket may consist of several layers of increasingly larger particles from sand to erosion control stone.

For best results, use a well-mixed rock size and irregular-shaped rock preferably with a three-point bearing. Irregular-shaped rock establishes a better locking capability. The stone size must be adequately shaped and heavy enough to resist wave action. Excessive settlement, an increase in voids, the loss of filter material, erosion occurring at the top, toe, or the ends of the protection can result due to the use of undersized or inadequate outer stone. The voids between the stones need to be small enough to prevent a wave action washout of the underlying materials. Special care must be taken to prevent damage to fabric materials when placing the outer stone.

Riprap should be a well-graded mixture with 50% by weight larger than the specified design size. The diameter of the largest stone size in such a mixture should be 1.5 times the d_{50} size with smaller sizes grading down to one (1) inch.

Flanking can occur adjacently to the bank protection used. The ends of the protection should be transition into the adjoining stable section of the bank or shoreline. If no stable sections exist, then the protection used should continue or be protected by tying each end into the bank. Adequate height is another important design feature that prevents overtopping by waves or run-up. If settlement occurs after construction, additional height may be added to avoid future overtopping.

Construction techniques, dimensions of the area to be protected, size and gradation of the riprap, the frequency and duration of flow, difficulty and cost of maintenance, and consequence of failure should be considered when determining the thickness of riprap linings. The minimum thickness should be 1.5 times the maximum stone diameter, but in no case less than six (6) inches.

Divert stream flow away from the work area. Install sediment filter fabric or other sediment removal material between the stream and the work area. Shape the top of the bank to divert surface runoff from passing down over the slope. Excavate the trench to a depth below expected scours and to dimensions developed in the design. Install the rock in a uniform matrix to the design height. Smooth the top to join with the existing bank. Install tiebacks into the streambank at the upstream and downstream ends. Vegetate or apply soil bioengineering measures as needed upslope.

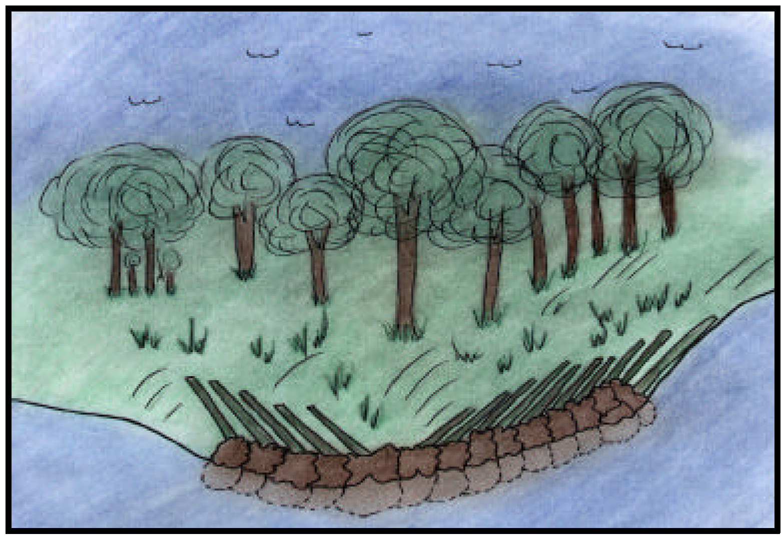
Arrange for integration of vegetation and soil bioengineering both in the rock riprap and upslope of it. Plan to install the work during the periods when least effect to the stream biota will occur. Obtain all required permits.

Protect existing streambank vegetation wherever possible. Establish access routes to minimize impacts on stream corridor vegetation. Operate equipment from top of the bank wherever possible. If there is insufficient equipment reach, consider ramping an access by using fill material rather than bank excavation. The fill material can be removed and incorporated into the riprap as the equipment progresses.

ROOTBALL OR ROOTWAD PLACEMENT.

(Information obtained from USACE Walla Walla District and extracted from "Interagency Streambank Corridor Restoration Handbook.")

Where undercutting by a river or stream occurs, rootwads/rootballs can be embedded on the riverbank and deflect flow against the bank. The stems will cause the snags to face downstream and resist forces to remove the bank. Their buoyancy even prevents them from being sucked into the scour holes they create. Area dominant with woody species in the riverine environment are best used for rootwads or rootballs. The snags from the rootwads/rootballs can be repositioned at key locations to protect the riverbanks as well as islands and levees and provide fish habitat.



Rootwads/Rootballs **Figure 27**
adapted from Walla Walla USACE

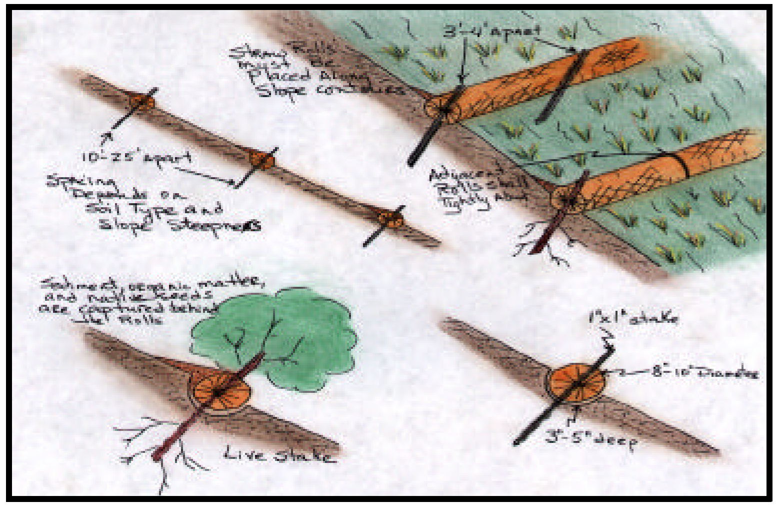
Bank placed materials, such as rootwad/rootball, can be placed alone or in series along the bank, generally along the outside bend of meanders. They are keyed into the bank so that high velocity flows cannot scour behind or underneath them. Figure 27 illustrates rootwads/rootballs. These type of revetments provide effective streambank erosion control in higher velocity streams, trap sediment between components, support restoration of slope vegetation, distribute flow velocities and instream sediments for fishery use, and provide an abundance of cover and shading.

Install a footer log at the base and parallel to the streambank at its midsection. Use boulders to anchor the footer log against floatation. Excavate trenches into the bank to accommodate the rootwad/rootball boles (eight (8) to 12 feet). Orient the trenches to allow placement of the root mass in a way that faces slightly towards the direction of flow and to allow the brace roots to be flush with the streambank. Backfill and combine vegetative plantings and soil bioengineering systems behind and above the rootwads/rootballs. These can include live stakes and dormant post plantings in the openings of the slope below bankfull stage. Place live stakes, fascines and other treatments above. If bank fill material will be subject to erosion flows, then treatments should be used to stabilize the banks above the revetment.

STRAW ROLLS.

(Information extracted from "Erosion Draw.")

Straw rolls are manufactured from straw that is wrapped in tubular black plastic netting. They are approximately eight (8) inches in diameter by 25-30 feet long. Rolls are placed and staked along the contour of newly constructed or disturbed slopes. This type of measure is intended to capture and keep sediment on the slopes. Straw rolls are useful to temporarily stabilize slopes by reducing soil creep and sheet and rill erosion until permanent vegetation can get established. Installed, straw rolls shorten the slope length, thereby interrupting the raveling and rilling processes, and reduce the slope steepness. They catch soil material that moves down the slope by the freeze/thaw processes. Organic matter and native seeds are trapped behind the rolls, which provide a stable medium for germination. Straw rolls trap fertile topsoil and retain moisture from rainfall, which aids in growth of tree seedlings planted along the upslope side of the rolls. Figure 28 illustrates straw roll installation.



Straw Rolls **Figure 28**
adapted from "Erosion Draw"

Sites appropriate for straw rolls are:

- Slopes susceptible to sheet and rill erosion;
- Slopes producing dry ravel;
- Slopes susceptible to freeze/thaw activity; or
- Slopes difficult to vegetate because of soil movement.

Straw rolls are not intended for use in concentrated flow situations.

It is important, especially on steeper slopes, that a sufficient trench is constructed in which to place the roll. Without it, the roll will not function properly, runoff will scour underneath it, and trees or shrubs planted behind the roll will not have a stable environment in which to become established. Straw rolls will last an average of one (1) to two (2) years. These rolls can be staked with willow stakes. The moisture retained by the roll with encourage willow establishment.

Advantages:

- Straw rolls are a relatively low-cost solution to sheet and rill erosion problems.
- They can replace silt fences or straw bales on steep slopes.
- Rolls store moisture for vegetation planted immediately upslope.
- Plastic netting will eventually photodegrade, eliminating the need for retrieval of materials after the straw has broken down.
- Straw becomes incorporated into the soil with time, adding organic material to the soil and retaining moisture for vegetation.

Disadvantages:

- Rolls only function for one (1) or two (2) seasons.
- Pilot holes through the rolls must be pre-driven with a metal rod.
- If not installed properly with an ample trench, rolls may fail during the first rain event.
- Straw rolls may require maintenance to ensure that the stakes are holding and the rolls are still in contact with the soil.

Construction Specifications:

- Prepare the slope before the wattling procedure is started.
- Shallow gullies should be smoothed as work progresses.
- Dig small trenches across the slope on contour, to place rolls in. The trench should be deep enough to accommodate half the thickness of the roll. When the soil is loose and uncompacted, the trench should be deep enough to bury the roll 2/3 of its thickness because the ground will settle.
- Critical that rolls are installed perpendicular to water flow, parallel to slope contour.
- Start building trenches and install rolls from the bottom of the slope and work up.
- Construct trenches at contour intervals of three (3) to 12 feet apart depending on steepness of slope. The steeper the slope, the closer together the trenches.
- Lay the roll along the trenches fitting it snugly against the soil. Make sure no gaps exist between the soil and the straw wattle.
- Use a straight bar to drive holes through the wattle and into the soil for the willow or wooden stakes.
- Drive the stake through prepared hole into soil. Leave only one (1) or two (2) inches of stake exposed above roll.
- Install stakes at least every four (4) feet apart through the wattle. Additional stakes may be driven on the downslope side of the trenches on highly erosive or very steep slopes.

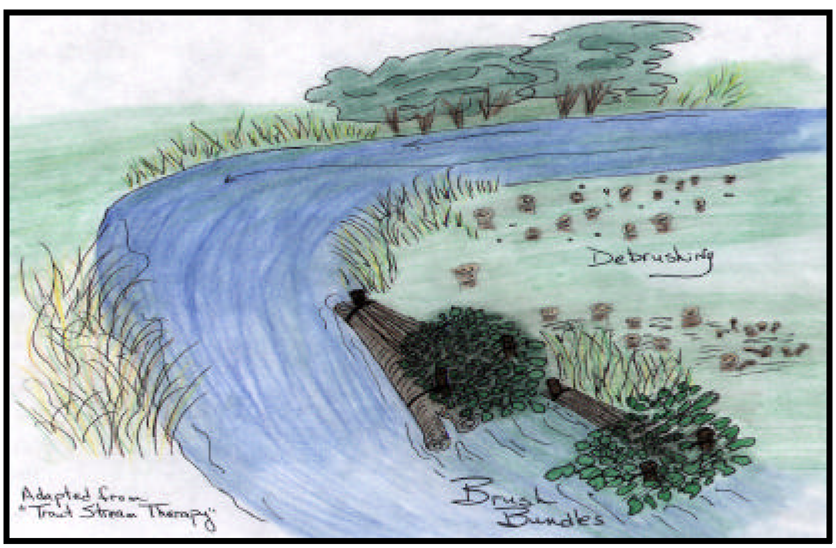
STREAMBANK DEBRUSHING, BRUSH BUNDLES AND BRUSH MATS.

(Information extracted from "Trout Stream Therapy" and "Streambank Corridor Restoration Handbook" and obtained from the EPA's Office of Wetlands, Oceans and Watersheds.)

Streambank Debrushing. The Department of Natural Resources of Wisconsin introduced streambank debrushing to initiate a series of changes in riparian zones and stream channels that would support trout-carrying capacity and also make these streams easier to fish. These changes include replacement of woody vegetation with stands of herbaceous vegetation more resistant to stream flow erosion along current-bearing banks. "Consequently, better quality scour pools gradually develop beneath the hardy turf. Deeper, narrower stream channels also develop when herbaceous vegetation proliferates in response to increased sunlight and encroaches from the stream banks along shallow inside bends and along straight channel reaches (Hunt)." One other benefit of reducing a shade canopy is a greater growth of rooted aquatic plants that, in turn, stimulate increased production of trout food organisms and provide more instream cover for trout.

An issue to consider on a site-by site basis before removing woody shade canopies is potential harmful warming of the stream due to increased exposure to solar heating. Although, environmental conditions for trout in very cold, small streams may actually benefit if temperature regimes can be raised during the summer to increase the hours of water temperatures which are more favorable for trout growth. Figures 29 and 30 represent streambank debrushing along with two other techniques.

Brush Bundles. Much of the cut brush is promptly put to good use. One use is constructing brush bundles. Brush bundles vary in size, placement location, and design, but the most common procedure is to put them along the inside edges of stream bends, where deposition of stream-borne materials naturally occurs as illustrated in Figure 29. Bundles placed here accelerate the deposition process and speed up



Brush Bundles and Debrushing **Figure 29**
adapted from "Trout Stream Therapy"

establishment of stable encroaching banks that help to concentrate stream flow toward the outside bends. This also deepens the stream channel, and increases undercut banks. Pools beneath undercut banks provide most of the hiding covers for adult trout in small streams.

Brush bundles placed along the shallow side of stream channels also provide additional temporary cover (4-5 years) for small trout and attachment structure for invertebrates.

A simple technique in constructing a brush bundle consists of placing three (3) wooden stakes in a triangular configuration just at the tip of an inside bend. Each stake protrudes above the water three (3) to four (4) feet. Pile cut brush within the triangular area, with the butt ends toward the bank and stems extending downstream. Lash several butts together with synthetic cord that will not rot away in a year or two and tie to the upstream stake. Tie anchoring cord across the brush from one of the lower stakes to the other to help consolidate the brush mass and provide additional stability.

If large dead or undesired trees have also been removed, anchor portions of the main trunk along the outside edges of brush bundles to provide longer functional life to the bundles and help deflect stream flow to outside bends.

Brush Mats. Along excessively wide and shallow reaches of a stream that tend to carry above-normal sediment loads, brush mats can be installed if enough cut brush is available. Use this technique where exposed banks are threatened by high flows prior to vegetation establishment. These mats consist of interwoven, crisscrossed bushy material.

Brush Mats and Debrushing **Figure 30**
adapted from "Trout Stream Therapy"

With this technique, a series of tie-down cords and stakes is used to compact and stabilize each mat is used. Brush mats, like their smaller brush bundle versions, help both to narrow and to deepen the stream channel and provide in-stream cover for trout. Brush mats should not be used on slopes which are experiencing mass-movement or other slope instability. See Figure 30.

Installation of brush mats is as follows:

- Select branches three (3) to ten (10) feet long and approximately one (1) - 2.5 inches in diameter depending on the site. Branches must be flexible to conform to slope surface irregularities. A large quantity of the branches will be needed.

- A typical installation involves anchoring the lower edge of the brush mat in a trench, using a fascine to anchor and protect the lower edge from undermining.

- Grade the streambank uniformly to a maximum slope of 2:1. A slope of 3:1 or flatter is recommended.

- Harvest and stockpile the branches. Prepare and stockpile dead stout stakes. Prepare live stakes and live fascine bundles.

- Beginning at the base of the slope, excavate a trench parallel to the water surface and large enough to accommodate a live fascine and the basal ends of branches. Place the fascine in the trench and only drive stakes in half way.

- Above the trench, install alternative live and dead stakes at two (2) foot square spacing. Drive to leave one (1) foot of stake exposed.

- Place branches in a six (6) -12-inch thick layers with the basal ends under the fascine.

- Stretch No. 16 smooth steel wire diagonally from one (1) dead stake to the next by tightly wrapping wire around each stake about six (6) inches from its top. Drive stakes until the branches are firmly pressed to the slope. Place soil on top of the fascine leaving the top slightly exposed. Fill voids between the branches of the brush mat with loose soil and water repeatedly to fill voids with soil and facilitate sprouting; however, some branches should be left partially exposed to the surface.

Occasional (four (4) to five (5) year frequency) refurbishing of brush bundles or brush mats is an option worth pursuing if sufficient near-stream material is available to cut, and where shallow a water habitat for young trout is a high-priority need. The structure may require protection from undercutting by placing or burying stones on the lower edge. Brush mats are generally resistant to waves and currents and provide protection from the digging out of plants by animals. Disadvantages include possible burial with sediment in some situations and difficulty in making later plantings through the mats.

TRAINING FENCES.

(Information obtained from USACE Walla Walla District.)

Training fences, as shown in Figure 31, are designed to catch debris and physically deflect about 50 percent of the incident flow. The sediment-laden water penetrating the fence is slowed sufficiently to drop the heavier fraction of entrained soil on the downstream side. The energy-reducing mechanism is primarily the head loss from penetrating the fence twice - first to get into the bank zone and again to get out. If the protected reach is long enough and steep enough to support rapid flow, it must be subdivided with additional fences or structures (such as gravel berms) to further impede flow.

Training Fence **Figure 31**

adapted from USACE Walla Walla District

Wood or timber fences can be built to deflect river flows away from and around islands under attack. Deflection fences consist of posts spaced at close interval and planks placed horizontally with boards fastened directly to the posts as close together as possible without totally obstructing the flow. Posts should be 12 to 18 inches in diameter. Rails should be at least two (2) to four (4) inches thick, depending on post spacing.

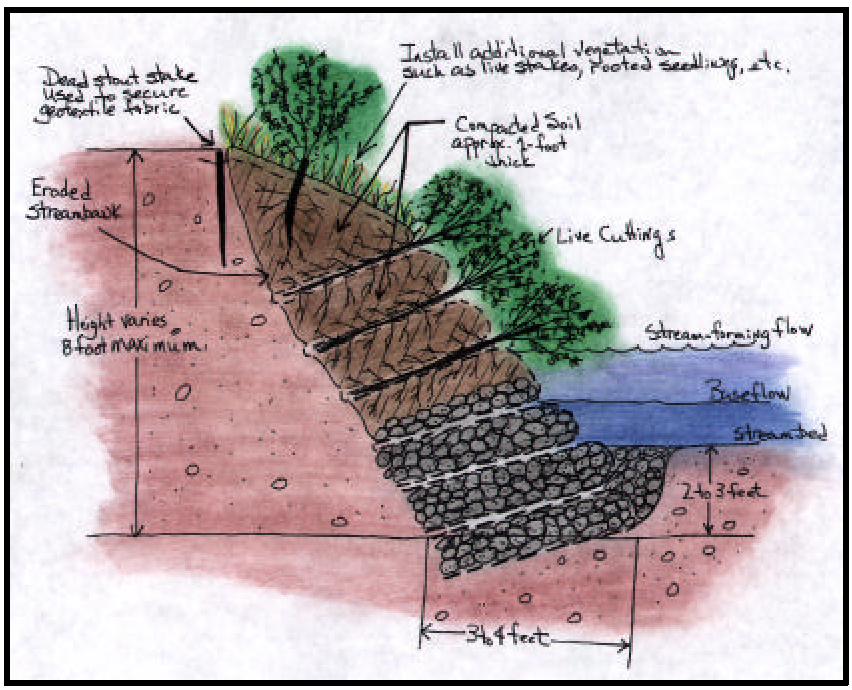
Wooden structures will eventually rot away above the low water line, leaving only the new bank. Permanently submerged timber will remain to provide scour protection for many years. Treated wood (environmentally approved for in-water use) and metal structures could last much longer. It is unlikely, however, that metal structures could be designed in a way that would make them aesthetically acceptable.

VEGETATED GEOGRIDS.

(Information extracted from Gray/Sotir and obtained from the U.S. Dept. of Agriculture.)

Vegetated geogrids are similar to branchpacking (or brushlayering) except that natural or synthetic geotextile materials are wrapped around each soil lift. The brush is placed in a crisscross or overlapping pattern so that the tips of the branches protrude just beyond the face of the fill, where they retard runoff velocity and filter sediment out of the slope runoff (Gray/Sotir). See Figure 32. This technique is useful for rebuilding eroded streambanks or configuring new banks in stream realignment projects. It also provides riparian vegetation for other functions.

Vegetated geogrids can be installed on a steeper slope than normal brushlayering. A slope of vegetated geogrids have a higher initial tolerance of velocity than its brushlayering counterpart. This technique can be complex and expensive and require large outlays of both labor and equipment to install. Systems more than seven (7) feet in height or 20 feet in length should have an engineering analysis for slope stability.



Vegetated Geogrids **Figure 32**
adapted from U.S. Department of Agriculture

A local source and good supply of live dormant branches, such as willow, alder, and dogwood, which may range from 0.5 to two (2) inch in diameter needs to be identified. The branches should be long enough to reach the back of the trench to be filled and should be extended slightly beyond the surface of the completed slope. Volume estimates of fills required should be made and fill sources located. Estimate the surface area of geotextile which will be required. Determine the number and length of live stakes and plantings needed. Dead stakes will be required to anchor the geotextile at the top of the slope.

If needed, select an approach to stabilize the toe of the slope (rock riprap, live cribwall, log armoring or others), determine the source of materials needed, and provide sediment control to protect aquatic species.

Divert any surface water which could flow over the bank. Excavate the base trench to a level below an expected scour in the streambed. Make the trench three (3) to four (4) feet wide and sloping slightly toward the streambank. Fill to the baseflow with rock riprap sized for protecting the toe, or alternate use of log cribbing, gabions or other toe protection techniques. Starting at the back of the trench, wrap the leading edge of geotextile beneath the final lift of toe protection. Continue placement of the geotextile by overlaying the toe protection surface.

A vegetated geogrid installation begins at the base of the slope and proceeds upward. A vegetated geogrid structure should be supported on a rock toe or base and be battered or inclined at an angle of at least 10 to 20 degrees to minimize lateral earth forces (Gray/Sotir).

Wrap the geotextile back over the branch layer. Place and compact soil material over the branches in a lift thickness from one (1) to two (2) feet along the slope. Reduce the lift thickness on steeper slopes or those which may experience seepage.

Limit the total height of layers to approximately seven (7) to eight (8) feet, including subgrade, unless a design professional has performed analyses and determined that stability is assured at greater heights and the resulting design is strictly followed.

Where seepage is occurring in the slope, consider installing a relief drain at the rear of the trench and above the base flow level. This will reduce potential soil pore pressure and protect against future slumping.

VEGETATION/REVEGETATION.

(Information obtained from the USACE Waterways Experiment Station and extracted from "Trout Stream Therapy," "Erosion Draw.")

Vegetation, in many project areas, is an excellent way to provide erosion control and also reduce sedimentation problems. Vegetation is also used on dredged material sites when creating islands and barrier islands.

Responsible planning, knowledge of the project area or site, selection of suitable and regional plant species, finding appropriate plant materials, proper handling of the plant materials, and establishment techniques, together, will increase the chances of successful plant development.

In finding appropriate plant materials, the typing of planting stock, classes of plant materials, seasons of planting, acquirements of plant materials, and the quality of plant materials are important features. Acquirement of plant materials includes the collection of seeds and plant materials, production of plant materials, location of materials that will be used on-site for cuttings, wattling, and the writing of specifications and contracts. The handling of the plant materials is a sensitive matter in order not to cause stress from the production facility or collection site to the actual project site.

As with any project, determination of objectives is an important aspect of any vegetation project. The following factors should be considered when choosing objectives:

- If a decrease in water temperature and improvement of fish habitats are a part of your objective, more shade will be produced with tall and/or wide canopy species planted on the south side of the water rather than with shrubs or short trees.

- If wildlife habitats are desired, determine the species of wildlife and their needs.

- If aesthetics are a part of the objectives, select species that have colorful flowers, species that flower in different months, or species that have colorful berries or fruits.

- If the revegetation site is between the public and the water, low growing shrubs might be preferable to taller shrubs or short trees so the view is not impaired.

- If bank stabilization is a part of the objectives, rhizomatous woody and herbaceous species planted together will give a much better "wall" of protection than a single species will.

- Are permanent structures desirable, or should temporary structures that will disintegrate over time be used? Temporary structures will allow the vegetation to become well established before it is exposed to full wave action or other erosive forces.

The equipment and/or tools needed for a revegetation project, which includes cuttings and transplants, will depend on the project plan, the size of plant materials, soils and size of the project. These tools may include: picks, mattocks, and shovels for site preparation; shovels, spades or tile spades for planting larger plants and trenching for wattling and brushlayering; and dibbles for planting smaller plants and cuttings. Star drills and hammers may be needed to plant cuttings in cemented soils. Power augers may be useful on large sites. Heavy hammers and sledges are needed for staking the job, driving stakes for fencing or cages for plant protection, and driving stakes in the installation of wattling. Chain saws, lopping and hand pruning shears, and hatchets may be needed for preparation of cuttings and materials for wattling, brushlayering and brush matting. Materials that may be needed are fertilizers, fencing, wiring for plant protection cages, and stakes for holding plant protection cages in place and for wattling. Each project will have its own requirements. This technique, in some cases, can be done on a volunteer type base as shown in Figure 33.

Community Tree Planting **Figure 33**

Photo taken by Seattle District - USACE

If fertilizer is used, the holes dug for the plants, should be deeper than needed for the plant size. The fertilizer should be mixed thoroughly in the bottom and covered with several inches of backfill to avoid burning of the plant roots. Use only the quantities of fertilizer recommended by the manufacturers. Planting should be done immediately after digging the holes to reduce drying of the backfill. The use of mulches is a debatable issue on project sites subject to flooding. Plastic mulches may reduce aeration when the plants are flooded and organic mulch will float away. If a growing season will occur between planting and flooding season, the mulches can increase plant survival.

In seeding the project area, there are several methods to use, keeping in mind the costs vary with the type of method used. Hydro seeding is an alternative where flooding does not coincide with the germination stage. Woody species usually cannot be established this way because the seeds are not planted beneath the soil surface. The costs will vary with the choice of species, rates of the seeding process, choice of mulch as binders, size of job, equipment needed, accessibility to the project site, etc. Average costs for this process range from $700 to $1,000 per acre. For gently sloped sites, the use of modified range drills can be used as a seeding process. Direct seeding or spot seeding can be used to establish woody species. Crop dusting is another method of seeding.

Plant protection is important at some project sites, as some animals can cause damage by browsing, trampling and eating. Wire cages, hardware cloth, and fencing are types of protection that can be implemented.

Making sure the seeds and/or plants receive sufficient amount of water will increase the growth and survival. If the project site is subject to summer rainfall, then the concern of water is not so great. If not, irrigation is necessary. Some plant species that are tolerant of flood and drought, may just need irrigation for a couple of growing seasons and usually survive without further irrigation. Depending on plant species used and the project area, irrigation practices should be thought of in early planning stages as labor and costs could play a big factor.

Controlling weeds in a revegetation site is another issue to consider. Chemicals which will degrade rapidly into harmless compounds can be used and their use should be well away from any water. Mulches are another consideration for weed control. Another alternative is manual weed control.

Permanent Seeding.
(Information extracted from "Erosion Draw.")

Permanent seeding is to establish a permanent, perennial vegetative cover on disturbed areas from seed. It is used to establish permanent vegetative grass cover that will prevent soil detachment by raindrop impact, reduce sheet and rill erosion, and stabilize slopes and channels. Permanent seeding can be used in conjunction with erosion control blankets and mats to provide both temporary and permanent erosion control. Perennial grasses, when used with turf reinforcement mats, provide the fibrous root network which anchor the channel linings. These treatments can greatly increase the maximum permissible velocities that are very useful in stabilizing channels and grass-lined channels. Perennial grasses and legumes improve wildlife habitat and improve aesthetics.

Conditions where this practice applies are:

- Graded, final-graded or cleared areas where permanent vegetative cover is needed to stabilize soil.

- Construction areas which will not be brought to final grade for a year or more.
- Slopes designated to be treated with erosion control blankets.
- Grass lined channels or waterways designed to be treated with turf reinforcement mats, fiber roving systems, or other channel liners.
- Detention ponds and sediment basins as required.

Successful plant establishment can be maximized through:

- Good planning
- Knowledge of soil characteristics
- Selection of appropriate seed blends for the site
- Good seed bed preparation
- Timely planting
- Knowing that the potential for erosion will exist during the establishment stage
- Installing necessary erosion control practices such as diversion dikes, channels, and sediment basins prior to seeding
- A final graded site area, not to be disturbed by future construction activities
- Dormant seeding which offers a rapid start of grasses in the spring while protecting the soil during the winter
- Proper seed selection. This is very important. Choose climatically adapted perennial species that are long-lived, hearty and require low inputs of fertilizer, irrigation and mowing. Consider a locally occurring species for native grass establishment. Consider seed blends, because they are more adaptable
- Phasing; that is, as work is completed on upslope areas, permanent seeding practices are then applied to stabilize these areas
- Proper seed bed preparation and the use of quality seed which are important in this practice just as in temporary seeding. Failure to carefully follow sound agronomic recommendations will often result in an inadequate stand of vegetation that provides little or no erosion control
- Applying seed and mulch hydraulically to slopes that are steeper than 2H:1V. Slopes not amiable to site preparation or erosion control blankets should be treated with mulch and soil binder/tackifier products such as, bonded fiber matrix, acrylic copolymers or cementitious binders
- Mulching in most seeding practices. Straw mulch cannot be practically applied on slopes steeper than 2H:1V without anchoring
- Inoculating legumes with the proper rhizobium bacteria before planting. Pellet inoculation can be done in the field

Construction Considerations:
Timing:

- Apply permanent seeding on areas left dormant for one (1) year or more;
- Apply permanent seeding when no further disturbances are planned;
- To determine optimum seeding schedule, consult a local agronomist or erosion control specialist;
- Apply permanent seeding before seasonal rains or freezing weather is anticipated;
- Use dormant seeding for late fall or winter seeding schedules.

Seed Mixes:

- Use seeds appropriate to the season and site conditions;
- Consult local agronomist or erosion control specialists for seed mix;
- Use a seed blend to include annuals, perennials and legumes;
- Used seed rates based on pure live seed (PLS) of 80%. When PLS is below 80% adjust rates accordingly.

Site Preparation:

- Bring the planting area to a final grade and install the necessary erosion control Best Management Practices's (e.g., sediment basins and temporary diversion dikes).
- Divert concentrated flows away from the seeded area.
- Conduct soil test to determine pH and nutrient content. Roughen the soil by harrowing, tracking, grooving or furrowing.
- Apply amendments as needed to adjust pH to 6.0-7.5. Incorporate these amendments into the soil.
- Prepare a three (3) to five (5) inch deep seed bed, with the top three (3) to four (4) inches consisting of topsoil.
- The seed bed should be firm but not compact. The top three (3) inches of soil should be loose, moist and free of large clods and stones.
- The topsoil surface should be in reasonably close conformity to the lines, grades and cross sections shown on the grading plans.

Planting:

- Seed to soil contact is the key to good germination.
- Seed should be applied immediately after seed bed preparation while the soil is loose and moist. If the seed bed has been idle long enough for the soil to become compact, the topsoil should be harrowed with a disk, spring tooth drag, spike tooth drag, or other equipment designed that conditions the soil for seeding.

- Harrowing, tracking or furrowing should be done horizontally across the face of the slope. Seed to soil contact is key to good germination.
- Always apply seed before applying mulch.
- Apply seed at the rates specified using calibrated seed spreaders, cyclone seeders, mechanical drills, or hydroseeder so the seed is applied uniformly on the site.
- Broadcast seed should be incorporated into the soil by raking or chain dragging, and then lightly compact to provide good seed-soil contact.
- Apply fertilizer as specified.
- Apply mulch or erosion control blankets, as specified, over the seeded area.

Inspection and Maintenance:

- Newly seeded areas need to be inspected frequently to ensure the grass is growing.
- If the seeded area is damaged due to runoff, additional storm water measures may be needed.
- Spot seeding can be done on small areas to fill in bare spots where grass did not grow properly.

Hydraulic Planting

Hydraulic planting is a method of applying erosion control materials to bare soil and establishing erosion-resistant vegetation on disturbed areas and critical slopes. By using hydraulic equipment (hydroseeders and hydromulchers) seed, soil amendments, wood fiber mulch and tackifying agents, bonded fiber matrix and liquid copolymers can be uniformly broadcast, as a hydraulic slurry, onto the soil. These erosion and dust control materials can often be applied in one operation.

Hydraulic planting can be effectively used to establish vegetation intended to control erosion on steep critical slopes that cannot practically be treated with other methods. Hydraulic planting techniques, such as hydroseeding and hydrosprigging, are also used to establish stands of turf grass.

Hydraulic planting is a very effective method for applying seed and mulch material. This practice will uniformly distribute seed which can then be covered with protective mulch, ensuring favorable conditions for quick germination and growth.

Hydraulic planting is relatively more expensive than manual seeding and mulching, however, hydraulic planting generally requires less seed bed preparation - the soil surface may be left irregular with large clods, stones or rock outcroppings exposed.

On steep critical slopes, with limited accessibility and where mulch must be anchored and/or on shallow soils that restrict the use of erosion control blankets, hydraulic planting techniques will provide the most dependable results.

Hydraulic planting techniques should be considered or temporary and permanent erosion control, seeding and mulching for sites with the following conditions:

- Slopes steeper than 3H:1V that cannot receive adequate seed bed preparation and on which the mulch would be difficult to otherwise anchor.
- Where the slope surface is irregular with large clods, stones or a high percentage of rock.
- Where site conditions, such as irregular soil surfaces, existing vegetation, and shallow soils preclude the installation of erosion control blankets and mats.
- On sites where other soil stabilization, seeding, and mulching practices would require unacceptable levels of disturbance.
- Post-fire or rehabilitation sites which only are accessible by hydraulic application equipment. Remote locations with steep slopes may be reached with hoses.
- On sites where it is desirable to apply water, seeds and mulch in one operation.
- On critical erosion sites where the application of seed, fiber, fertilizer followed by the application of straw mulch and tackifier (the three-step process) is desirable.
- On sites where straw mulch has been applied and the straw needs to be anchored (tacked) with tackifiers or hydraulic mulches.
- On sites where a dust control is desired.

Design Considerations:

Hydraulic machines today are used to spray seed, tack down straw, bind the soil, seal the soil, or apply blanket-like coats of bonded fiber matrix (BFM). These materials are usually applied by spraying a slurry, often in one (1) application. The hydraulic mulching slurry is a thick viscous fluid which tends to resist flow when pumped to a tower-mounted discharge gun or through a hose. The thicker the slurry of hydraulic mulching material, the more difficult it is to mix and pump.

Types of Hydraulically Applied Materials for Erosion and Dust Control:

Seed and Fertilizer. Applying seed and fertilizer with water has many benefits. The seed blend can be distributed uniformly, the added mass increases accuracy and throw distance, especially for exposed, windy areas, and the pre-soaking and water accelerates germination and enhances the chance of survival. There is a risk that pellet inoculated legumes will have the beneficial rhizobium bacteria washed off in the slurry such that the legume will not be able to fix atmospheric nitrogen. Pellet enucleated legumes should be either dry applied or be hydraulically applied immediately after being placed into the tank with water.

Mulches. Hydraulically applied mulches include mulches made from wood fibers, paper fibers, combination recycled wood and paper fibers, and polyester and/or polypropolene fibers.

Tackifiers. Tackifers are typically used to anchor mulch to increase effectiveness of erosion control. Tackifiers used in conjunction with straw mulch is extremely effective in bonding the straw to itself and the soil surface, thus resisting movement by water or wind. Some tackifiers, such as those mode from polymers, plant muselage, or guar are extremely important to lubricate the slurries and increase application performance. Liquid formulations of acrylic co-polymers can also be specified alone to control erosion and dust. These products chemically bond and stabilize the soil surface.

Cememtitious Binders. These products are formulated from hydrated lime or gypsum are mixed with water, and applied to the soil with hydraulic equipment. Fiber mulch, seed and fertilizers are applied to the slurry and sprayed on in one application. These cementitious binders form a permeable crust on the soil surface which control water and wind erosion.

Bonded Fiber Matrix (BFM). Hydraulic matrix products are typically produced from longer fibers combined with tackifiers and binding agents that are hydraulically applied and conform to the ground and dries to form a bonded fiber matrix. Seed and fertilizer can be added to the slurry and applied with the BFM in one-step application. The BFM forms a thick permeable, 3-dimensional, continuous, blanket-like covering that holds soil and seed in place. BFM is generally applied at rates from 3,000 to 4,000 lbs/acre. Figure 33a illustrates three phases of a fiber roving system: fiber in the foreground, tackifier and seed in the middle and vegetation in the backside.

Fiber Roving System **Figure 33a**
adapted from Synthetic Industries Landlok® Applications

Mulching. Mulching is the application of a protective layer of straw or other suitable material to the soil surface. Straw mulch and/or hydromulch are also used in conjunction with seeding and hydroseeding of critical areas for the establishment of temporary or permanent vegetation.

Mulching with straw or fiber mulches is commonly used as a temporary measure to protect bare or disturbed soil areas that have not been seeded.

The purpose of mulching is to temporarily stabilize bare and disturbed soils, to protect the soil surface from raindrop impact, to increase infiltration, to conserve moisture, to prevent soil compaction or crusting, and to decrease runoff. Mulching also fosters growth of vegetation by protecting the seeds from predators, reducing evaporation, and insulating the soil.

BENDWAY WEIRS

(Information obtained from USACE's Waterways Experiment Station's Dave Derrick)

BENDWAY WEIRS
For Streams and Smaller Rivers:

Bendway Weirs with longitudinal peaked stone toe protection **Figure 34**
Ft. Belvoir, Va.

In a stream or river with unrevetted banks, a Bendway Weir is a low-level, upstream-angled stone sill, attached (and keyed into) the outer bank of a bend. The weirs are angled from 5 to 25 degrees upstream, built of a well graded stone with an upper weight limit of 650 to 1,000 pounds, spaced 50 to 100 feet apart, typically two (2) feet high at the stream end rising to four (4) feet at the bank end, with lengths varying from one quarter to one half the base flow width of the river or stream. Figures 34, 34a, and 34b shows Bendway Weirs under construction.

Bendway Weirs with longitudinal peaked stone toe protection
Figure 34a
Ft. Belvoir, Va.

Weirs are usually emergent during low flows. Emergent weirs act as spur dikes. When overtopped, hydraulic benefits are similar to large river Bendway Weirs, with important attributes being reduction of erosion on the outer banks of the bends by reducing near bank velocities, reducing the concentration of currents on the outer bank of the bend, and redirecting currents to improve flow alignment through the bend and crossing. Weir angle is critical due to the tight radii and short crossing lengths found in streams and smaller rivers.

Advantages of Bendway Weirs are:

Closeup of Bendway Weir **Figure 34b**
Ft. Belvoir, Va.

- Flow can be redirected and predicted (even downstream of the weir field);
- Weirs work best under high-flow, high-energy conditions;
- Flow within the weir field is considered controlled;
- Aquatic habitat is improved;
- Costs are comparative or lower than traditional methods; and
- Weirs blend well with other bank protection methods.

Some design considerations are:

- Project entrance conditions must be stable;
- Flow direction entering the weir field must be known;
- Some scalloping between weirs can be expected;
- Excessive scour upstream and downstream of the downstream weir has occurred in some projects; and
- Effects of the weirs downstream of the project (both beneficial and detrimental) must be considered.

The following are indicators that a system of Bendway Weirs are working:

- Failed material is not removed from base of eroded bank;
- Outer bank between weirs is stable and vegetated;
- Sediment is deposited on outer bank after high flow events;
- "Dogbone" shaped depositional patterns are formed between midpoints of weirs at the upper end of the weir field;

- Typically deeper pools are found between weirs at the lower end of the bend;
- Point bar scoured, at times a vertical face scoured on the Point bar (usually from mid-bend to downstream end of bend); and
- In some cases, low-elevation mud flats are deposited between bank ends of weirs.

This methodology is new, weirs have only been built in 22 locations and all monitoring has been short term (1993 to 1996).

Bendway Weirs provide a low cost and effective streambank protection because of the following:

- Can be designed in the field without a survey;
- Minimal disturbance and impact on the stream;
- Can be constructed using readily available equipment; and
- Design and construction can usually be accomplished in a week.

Very little modeling has been performed with Bendway Weirs in an unrevetted bend. Prototype uses have included bank stabilization, redirection of flow for highway bridge abutment protection, pollution abatement, stream restoration, pipeline crossing protection, and environmental restoration. Weirs have also been added to two (2) existing projects to enhance project effectiveness. Thirteen low-cost, innovative, landowner-financed, bank protection projects, using hand-placed and machine built stone weirs, sand filled GEOBAG and GEOTUBE Bendway Weirs, and weirs built from tree trunks, have been constructed to protect unimproved land (farmland). Each project was field-designed and constructed in one day using readily available equipment. In several cases, project costs averaged between $5 and $15.00 per foot of protected bank.

For Navigable Rivers:

In a navigable river, a Bendway Weir is a rock sill (5,000 pound maximum weight stone) located in the navigation channel of a bend, usually angled to 20 to 30 degrees upstream (into flow), spaced from 400 to 1,400 feet apart, varying in length from 400 to 1,600 feet, and level-crested at an elevation low enough to allow normal river traffic to pass unimpeded. The weir should be long enough to intercept a large percentage of flow at the river cross-section where the weir is located. Weirs are typically built in sets (4 to 14 weirs per bend) and are designed to act as a system to capture, control and redirect current directions and velocities through the bend and well into the downstream crossing. The last weir in the system can aim the flow (and channel thalweg) where one needs it.

Water flowing over the weir is redirected at an angle perpendicular to the longitudinal axis of the weir. When the weirs are angled upstream, water is directed away from the outer bank and toward the inner part of the bend. Results have indicated that construction of a series of Bendway Weirs in the navigation channel of a bend show the following improvements:

- The navigation channel through the bend and immediate downstream crossing is widened and better aligned;
- Deposition occurs at the toe of the revetment on the outside of the bend (increasing bank stability);
- Surface water velocities are more uniform across any cross-section;
- Flow patterns in the bends are generally parallel with the banks (not concentrated on the outer bank of the bend); and
- The thalweg of the channel is moved from the toe of the outer bank revetment to the stream ends of the weirs.

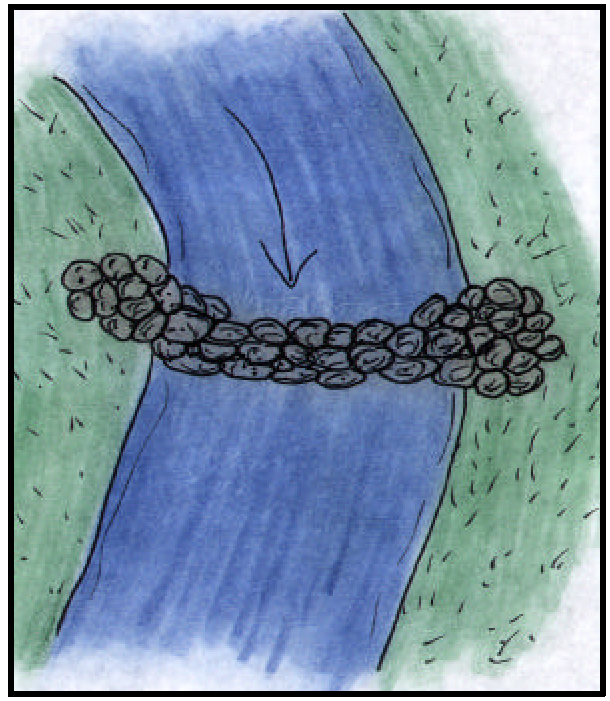
Bendway Weirs have been tested in 11 models at the Waterways Experiment Station. Weirs have been used to improve both deep and shallow-draft navigation, align currents through highway bridges, divert sediment, and protect docking facilities. Since 1989, over 140 weirs have been built in 16 bends of the Mississippi River. Prototype results have been outstanding. Analysis of the five (5) oldest weir installations show that from 1990-95 dredging was reduced by 80%, saving $3,000,000. In addition, towboat accidents were reduced, tow delay times at bends were reduced, sediment and ice management was improved, least tern nesting areas were undisturbed, aquatic habitat area was increased, and fish size and density in the weir fields increased (fivefold in some areas).

A set of Bendway Weirs that can change the direction of the Mississippi River is a powerful tool. A successful weir installation requires a thorough understanding of Bendway Weir theory and practice, and extensive knowledge of the stream or river in which the structures will be placed.

BOULDER OR LOG WEIR.

(Information extracted from "Erosion Draw.")

Boulder and log weirs are sills consisting of boulders or logs laced across the channel and anchored to the channel bank and/or bed. Boulder or log weirs are primarily used to collect and retain gravel for spawning habitat, or to create jump pools to facilitate fish passage. They may also serve to control bed gradients on degrading streams. See Figure 35 for an illustration of a boulder weir.



Boulder Weir **Figure 35**
adapted from "Stream Corridor Restoration Handbook"

These type of weirs are appropriate where spawning habitat is scarce and gravel size material can be captured during moderate flows. They also provide resting pools for fish migration on otherwise impassable stream reaches. These weirs may warrant consideration for controlling grade in streams undergoing bed degradation.

Boulder or log weirs are not appropriate in areas where rock or logs are not readily available. Also they may become low flow migration barriers. Log weirs will eventually rot away.

Boulders should be as large or larger than those naturally occurring in the stream. Large, angular boulders are most desirable to prevent movement during high flows. Quarry rock often is suitable for this. Rock soundness and durability are also important.

Logs should be durable species such as redwood or cedar and in sizes appropriate for the channel width (at least 12 feet longer than the width of channel at top of log weir level).

Consider several cross channel shapes to meet the intended need. Straight across, perpendicular to flow, installations work well for creating backwater. Diagonal orientations tend to redistribute scour and deposition patterns immediately downstream. Downstream "V's" or "U's" improve trapping of gravel. Upstream "V's" or "U's" provide mid-channel, scour pools below the weir for fish habitat, resting, and acceleration maneuvers during fish passage. Riffles usually are created in the deposition area downstream.

Slope the crest of the weir from the ties at the bank towards the thalweg. Provide a flow notch as desired or appropriate to concentrate flows during low discharges. Position the notch at the desired thalweg location. Install boulders or logs at the notch to provide as near a 90 degree over fall as possible.

Boulder weirs are generally more permeable than other materials and may not perform well for funneling of low flows. However, voids between boulders may be chinked with smaller rock and cobbles to maintain flow over crest.

Ends of the weir should be extended to stable points in each bank to avoid flanking during high flow events. This is referred to as a key. The amount of key depends on bank materials. Generally a key from five (5) to 10 feet is sufficient. Anchor to bedrock or large boulders where keys can not be fully established.

For boulders, select angular individuals in sizes ranging from three (3) to five (5) or more feet in diameter or at a minimum larger than the largest naturally occurring boulders in the stream. Choose boulders that are sound and dense.

Place boulders at planned locations in most situations boulders will need to be cabled. Cable together one to another with at least two linkage points at each end of the boulder. Anchor to fixed features such as bedrock or deadmen and bank keys. Secure cable using techniques such as drilling and adhesion. Keep cable lengths to just the space between boulders plus the drill hole depths. This will limit boulder movement. Drill holes in the sides of boulders, never the tops.

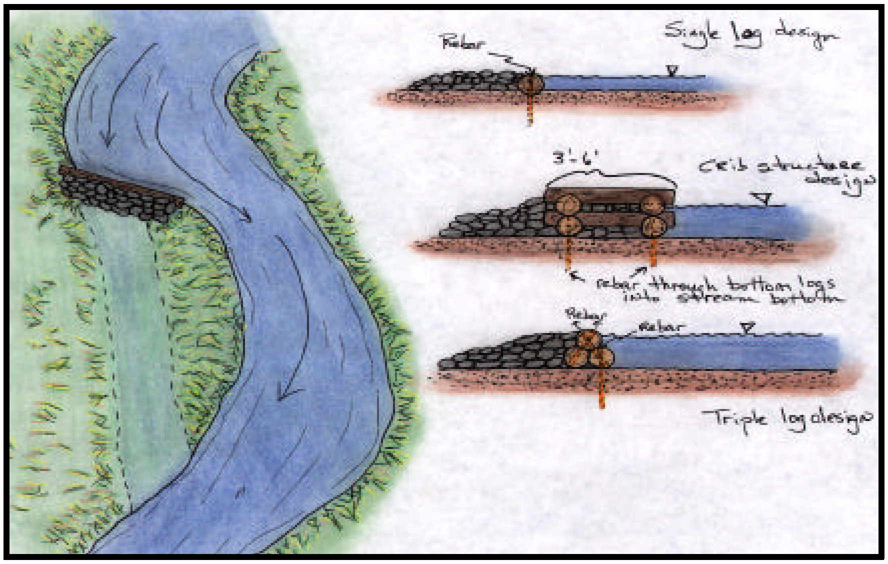
For logs, bury the sill log at streambed grade. Key the ends of the sill log at least six (6) feet into the banks. Successive logs may be placed in several configurations - straight, diagonally, and upstream “V”. Drill the next course of logs to receive 3/4" rebars at locations for securing to the sill log. Staple and secure hog wire or hardware cloth to the upstream side of the logs and form a blanket of it on the subgrade. Overlay and staple a geotextile blanket, then backfill with streambed size materials to the crest of the weir.

Construct a protective dike or mound over the top of the keyed bank locations to prevent overbank flows from eroding the bank and circumventing the entire installation.

CHANNEL BLOCK.

(Information obtained from the USDA's Forest Service.)

In any improvement project, top priority should be given to consolidating braided channels into one. Late summer flows moving through several small channels are often insufficient to hold fish, and in some cases will not allow up or downstream movement. By consolidating flow into a single deeper channel, additional fish holding habitat can be created. In addition, potential temperature problems can be avoided (wide, shallow areas tend to warm quickly), and migration routes restored.



Channel Block **Figure 36**
adapted from the Forest Service

Channel block structures, as shown in Figure 36, may also be used to maintain stream meanders where high water has created an oxbow. The structures hold normal or moderately high flows in the meander channel, but still allows flood waters to overflow into the blocked channel.

Since these structures are placed in critical areas bearing the brunt of flood waters, special care must be taken to insure stability. Single logs may be used with some success in small streams. However, triple log and crib structures give better results and are less likely to wash out in larger (over 15 feet wide) streams. As a general rule, triple logs can be used in relatively stable streams 15 to 25 feet in width. The log crib filled with gravel and rubble is generally more suitable for larger unstable streams. Triple logs or cribs tend to leak less water than single logs although single logs are easier and less expensive to install.

Generally, three (3) to four (4) single log structures or two (2) to three (3) triple log structures can be installed per crew day in 15- to 20-foot wide channels. One hand-filled crib may require from one (1) to two (2) days to construct.

Channel blocks are usually installed in braided channels or at the beginning of stream meanders where flood waters have created an oxbow.

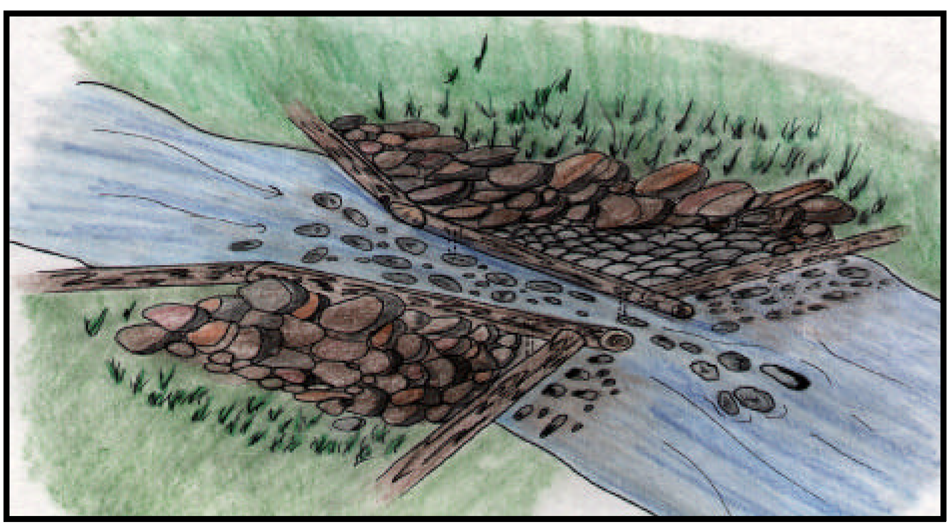
CHANNEL CONSTRICTOR.

(Information extracted from "Trout Stream Therapy.")

A channel constrictor is a measure used in high gradient straight reaches of channels. This structure provides good habitat cover under the face logs. The channel constrictor creates a partial dam which results in deepening of pool depth compared to the upstream and downstream reaches of the structure. Figure 37 illustrates a channel constrictor.

Large logs, about 20+ inches in diameter, should be used for the two (2) main face logs. To create extra habitat cover, notch out the bottom of the face logs. At the upstream butt end of the face logs, nail brace logs at a 45-degree angle and extend them well back into stream bank trenches. At the downstream end of the face log, offset a few inches from the butt end, nail brace logs at a 90-degree angle and extend them well back into stream bank trenches. The ends of the brace logs should be stabilized with stones or riprap as well as the area on the streambank side of the face logs. To prevent underside erosion, roadbase fiber mat and GEOWEB© (polyethylene grids consisting of honeycomb cells) can be used underneath the riprap.

This structure is very similar to a double wing deflector in that it is designed to narrow and deepen the channel. These structures are either paired or placed alone. The channel width is generally reduced up to 80%.



Channel Constrictor **Figure 37**

adapted from "Trout Stream Therapy"

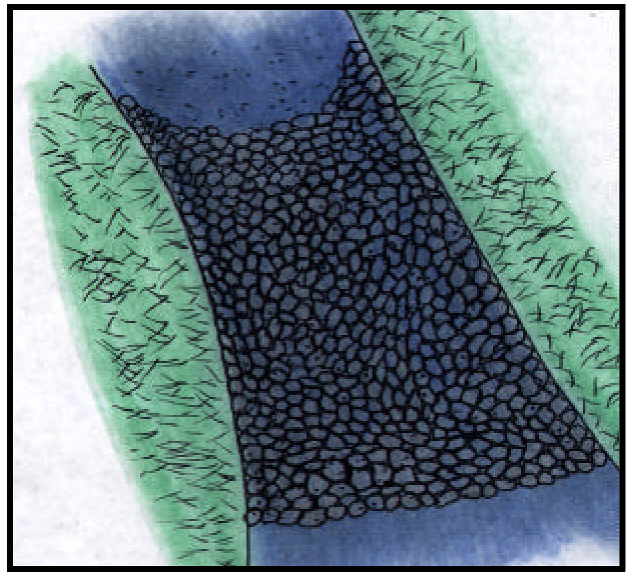
COBBLE OR GRAVEL LINERS.

(Information extracted from "Streambank Corridor Restoration Handbook.")

Cobble or gravel liners are placements of gravel or cobble size materials in the wetted perimeter of the channel, generally in reaches deficient in these size materials. These type of liners are used to provide spawning material for some fish species and to protect the channel bed from further deterioration.

Cobble or gravel liners may provide surface needed for fish spawning and benthic habitat for attachment organisms. These liners may also curb the degradation of the stream gradient in unstable reaches. Do not use this technique in reaches receiving heavy influxes of fine sediment which will cover the coarse materials. In such cases, consider watershed treatment as a means of reducing fine sediment loads, then place the liner.

When the liner is being considered to address erosion problems, an analysis of the tractive forces is needed to determine the appropriate sizes for the gravel or cobble mixture.



Cobble and Gravel Liner Figure 38
adapted from "Stream Corridor Restoration Handbook"

For spawning purposes (sometimes referred to as gravel seeding), consider the gradation of the gravel-cobble mixture needed for the target specie(s). Schedule the work well in advance of spawning runs.

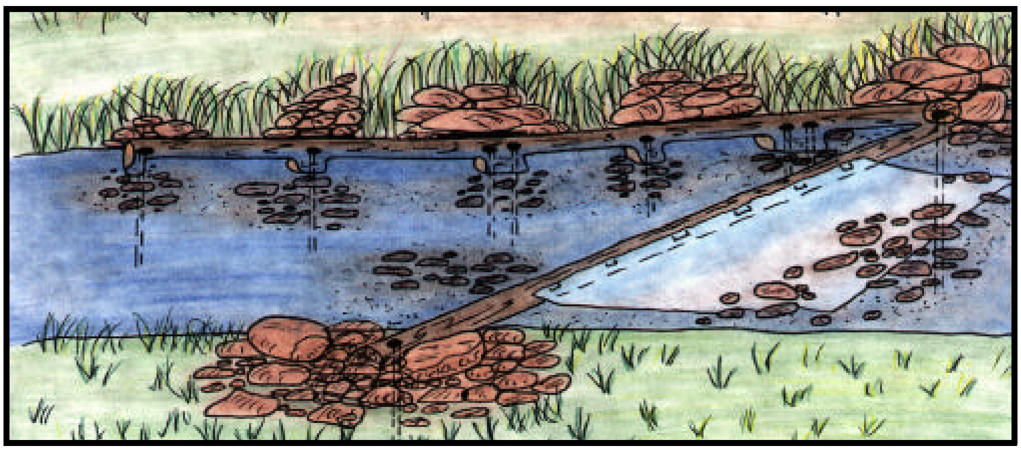
Major high flow events or watershed disturbances will require maintenance to remove fine sediment from spawning gravels or to replace eroded material. Techniques such as use of ripping equipment can be used to remove the fine sediment.

Consult the local fisheries biologist for windows of time appropriate for this in-stream activity. Cobble and gravel sizes should be appropriately sorted for the target fish species, only clean rock should be placed in the stream.

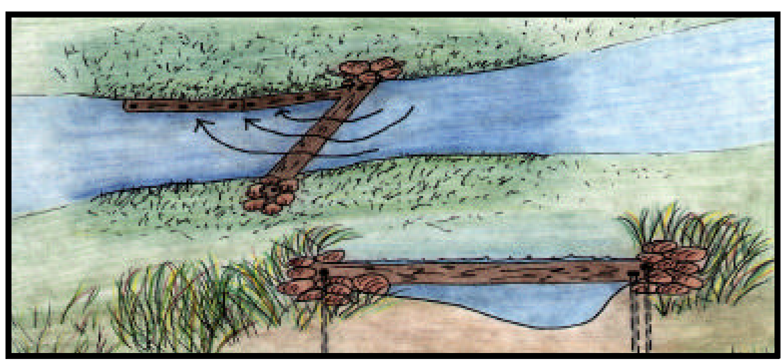
CROSS CHANNEL LOG AND REVETMENTS.
(Information extracted from "Trout Stream Therapy.")

The cross channel log, combined with revetments constructed at natural bends of a stream, will scour out a pool area and create habitat cover in high-gradient streams. This combination will also work well at the downstream end of a riffle to create pool areas and habitat cover. Figures 39 and 40 illustrate a cross channel log and revetment.

The revetment logs are pinned along the current-bearing bends of the stream using rebar rods. The underside of these logs are to be notched out to provide for the habitat cover. Cover the backs of these logs with stone/riprap to improve bank stability and reduce erosion. Attach the cross channel log at the upstream end of the revetment logs and angle it between 30 to 60 degrees downstream. The opposite side of the cross channel log should be several inches higher than where it is attached to the revetment logs. Each end of the cross channel log is to be pinned down with rebar and covered with stone/riprap. Roadbase fiber mat or other similar materials should be attached to the upstream part of the cross channel log and rolled out for several feet. This mat is to be buried with stream bed material to restore the natural gradient and to prevent undercutting at the cross channel log. This structure will direct the flow toward the revetment logs.



Cross Channel Log and Revetment **Figure 39**
adapted from "Trout Stream Therapy"

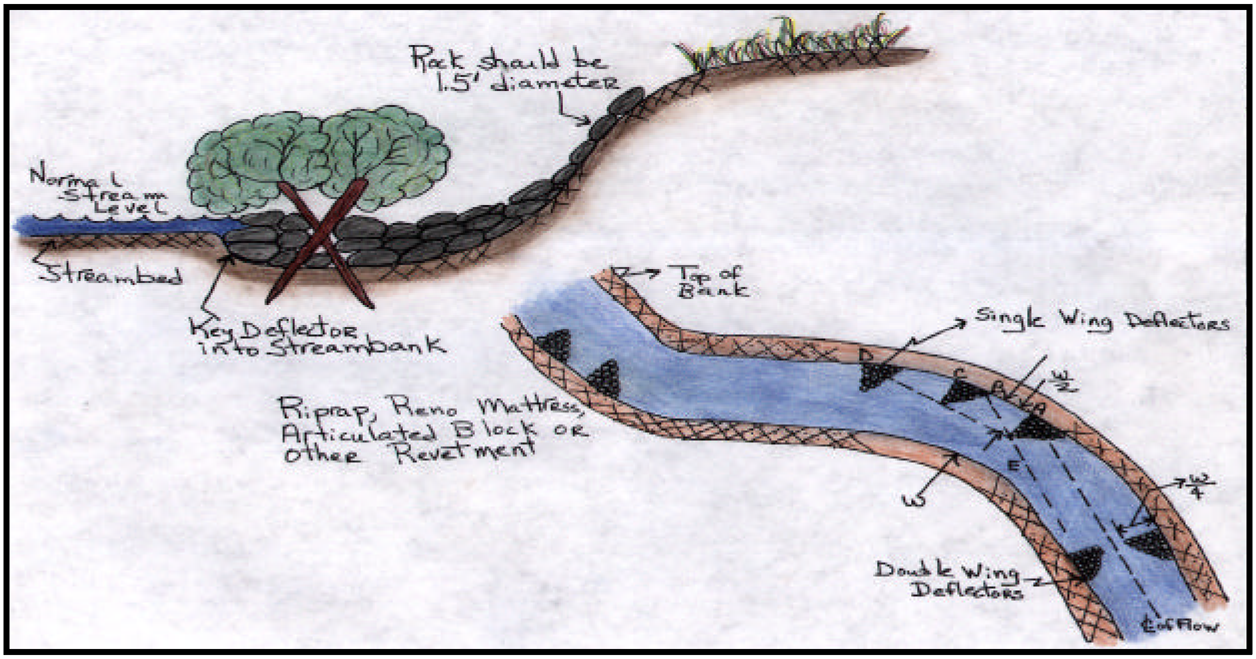


Aerial & Side Views **Figure 40**
Cross Channel Log and Revetment
adapted from "Trout Stream Therapy"

DEFLECTORS (ROCK).

(Information extracted from "Erosion Draw.")

Deflectors are structural barriers, in the form of groins or jetties, which project into the stream to divert flow away from eroding streambank sections. Stone and rock deflectors, used as instream structures, may also be useful for environmental and habitat enhancement. See Figure 41.



Rock Deflectors **Figure 41**
adapted from "Erosion Draw"

Construction Considerations:

- Live willow (or other riparian species) staking may be incorporated into the construction of the rock deflectors.
- The deflectors should be shaped in a 30-60-90 degree triangle with the 30 degree angle upstream and against the bank.
- Single wing deflectors extend 1/4 to 1/2 of the way across the stream.
- Double wing deflectors will extend no more than 1/4 of the way across the stream, opposite each other. The narrowest point between deflectors will be 1/2 of the stream width.

- In general, the first and last deflectors should be double wing deflectors. The general pattern will alternate between double wing and single wing, unless structures are intended to protect an outer bend. Then non-alternating, consecutive single wings may be required.

- The rock deflector should be constructed with a 1-1/2 foot minimum diameter rock. Larger channels will require larger rock.

- Rock deflectors should be keyed into the stream bottom a minimum of one (1) foot.

- The top of the rock should extend one (1) foot above normal stream flow (near bank) and slope down to a height of 1/2 foot above stream flow at apex.

- Deflectors should be contiguous with streambank protection measures.

  The following is a method of locating deflectors, or groins by using Figure 41.

  - Locate groin “A” at the intersection of the flow line and the eroding bank.

  - Locate point “B” by drawing line “E” parallel to flow line and crossing the tip of groin “A”.

  - Groin “C” is located such that AC is twice AB.

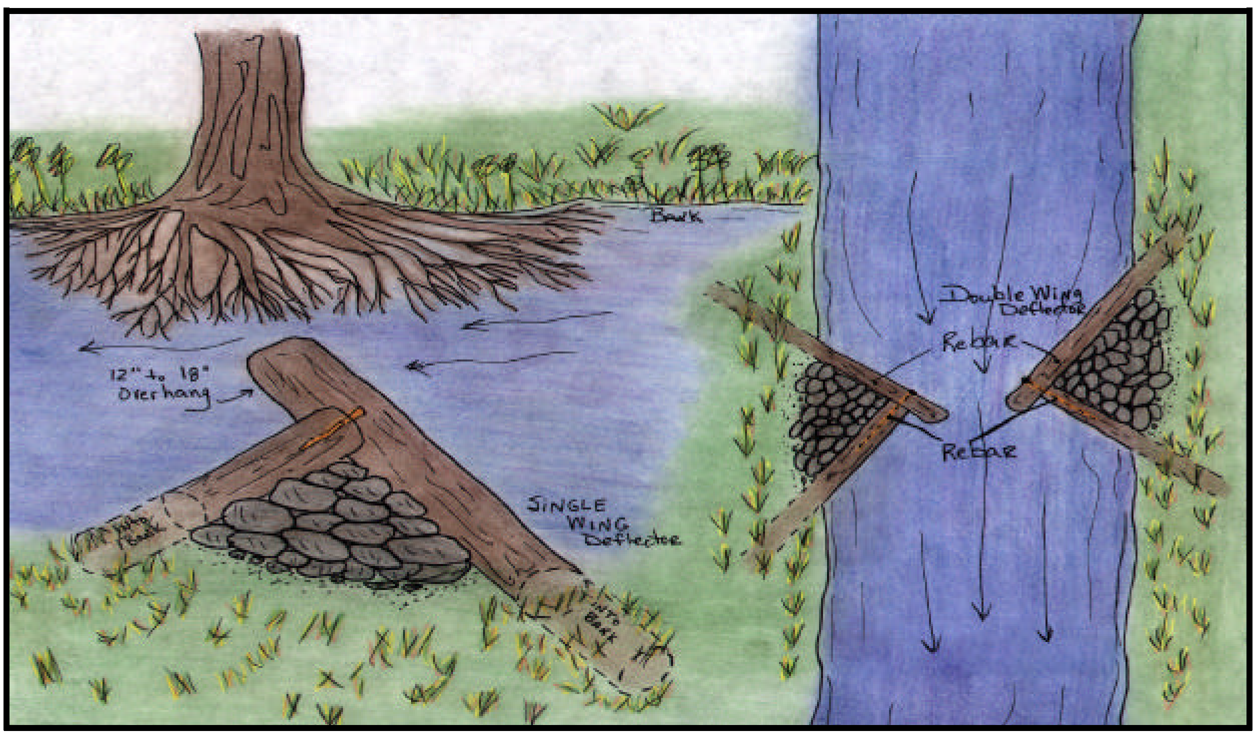
  - Groin “D” is located by projecting a line across the tips of groin “A” and groin “C”.

DEFLECTOR (SINGLE- AND DOUBLE-WING).
(Information obtained from the USDA's Forest Service.)

Single-Wing Deflector. Single-wing deflectors are normally inserted to constrict and divert flows so that stream meanders and pools are formed by scouring and relocation of fine sediment and gravel. See Figure 42 for an illustration of a single-wing deflector.

Logs should be at least 14 inches in diameter, except in the very smallest streams, and should be dug several inches into the streambed. The finished structure should rise six (6) to 18 inches above normal summer flows, but should never exceed streambank height. The higher the structure, the greater the scouring action will be during storm flow. Streambed width must be narrowed by 70 to 80 percent to achieve desired results.

Logs are held in place by 5/8-inch rebar at the junction of the two (2) logs, and by extending four (4) to six (6) feet of the main log into the streambank. In streams over 10 feet wide, 3/4-inch rebar, 48 inches long, should be driven through the main log into the stream bottom three (3) to six (6) feet from the tip of the structure.



Single- and Double-Wing Deflector **Figure 42**
adapted from the Forest Service

The main deflector log is placed at approximately a 30- to 45-degree angle to the streambank. The brace log is pinned to the main log 18 to 24 inches from the tip at approximately a 90-degree angle. This angle can vary somewhat, but should be such that waters overtopping the structure spill toward the center of the stream, rather than the streambank. Large flat rocks should be used for fill material when available, and placed shingle fashion for greater stability. Sod or soil and seed can be planted as a final measure to insure stability and improve aesthetics. Where flooding is a problem, the sod can be held in place by fine mesh wire or similar material.

Deflectors are quite versatile and can be placed in sites ranging from steep gradient chutes with heavy rubble bottoms, to wide shallow flats with sand or silt substrate. The most suitable locations are in wide shallow riffles or flats. When possible, water should be diverted into a relatively stable section of streambank. Ideal locations are where water is diverted into large boulders, overhanging trees or stumps, and sections of bank with interlocking root systems that can be undercut without sloughing significantly. Where sloughing would occur, an abutment or cover log can be added to hold the bank in place and to provide overhead cover. Where water is diverted against boulders, stumps, or other stable objects with a short span, the apex or tip of the deflector should be placed opposite or slightly upstream from the object. Where cover logs or extensive root mats provide a longer surface, the tip of the deflector should be located approximately one-third of the distance above the lower end of the log or root wad. By placing the deflector towards the lower end, the constriction or damming effect can create deeper water along the entire upper two-thirds of the log. These devices are suitable in streams up to 30 feet or more in width.

Deflectors are significantly less expensive to install than dam type structures, and can be placed in sections of stream where streambank height is too low for dams. They are also suitable for use in streams too wide for dams.

When maximum depth is the objective, dam type structures generally create a deeper scour pool than deflectors. In high gradient reaches with flows exceeding three (3) feet per second and substrate composed of large rubble or other coarse material, dams that break gradient and more effectively reduce current velocity generally provide better cover and resting or holding areas.

Three (3) to four (4) deflectors can be installed per crew day in streams 10 to 15 feet wide.

Double-Wing Deflector. The double-wing deflector is used to create mid-channel pools through scouring action in shallow sections of streams. See Figure 42 for an illustration of this type of deflector.

This combination of structures includes two (2) single-wing deflectors placed on opposite streambanks with the two (2) apex's narrowing the stream channel by approximately 80 percent (i.e., a 20-foot wide channel would be narrowed to four (4) feet). This degree of constriction in gravel and small rubble usually results in a scour pool extending 18 to 24 inches under the tip of each deflector.

This combination of structures is especially suitable for shallow sections of stream where the gradient is too steep for effective deflector and cover log combinations, and where banks are too low to install wedge or K-dams.

Double-wing deflectors can also be used in low gradient sections, but in most cases, the small meanders created in such areas by a series of deflector-cover log combinations are an advantage not provided by the double wing deflector.

The double-wing deflector is suitable for use in situations where deflector-bank logs and small dams are not as effective or feasible. If installed properly, scour pools equal in quality to those produced by small dams can be created at less cost. Maintenance, in addition to initial cost, is significantly less than on small dams. Double-wing deflectors are suitable in streams up to 30 feet or more in width.

These structures provide only one (1) break in gradient or resting area (the scour pool), while dams often provide a small flat or resting area above the structure in addition to the plunge pool.

The paired structures can, in most cases, be installed at two (2) locations per crew day in smaller streams (10 to 15 feet wide). In large streams, one and one half structures per day would be realistic.

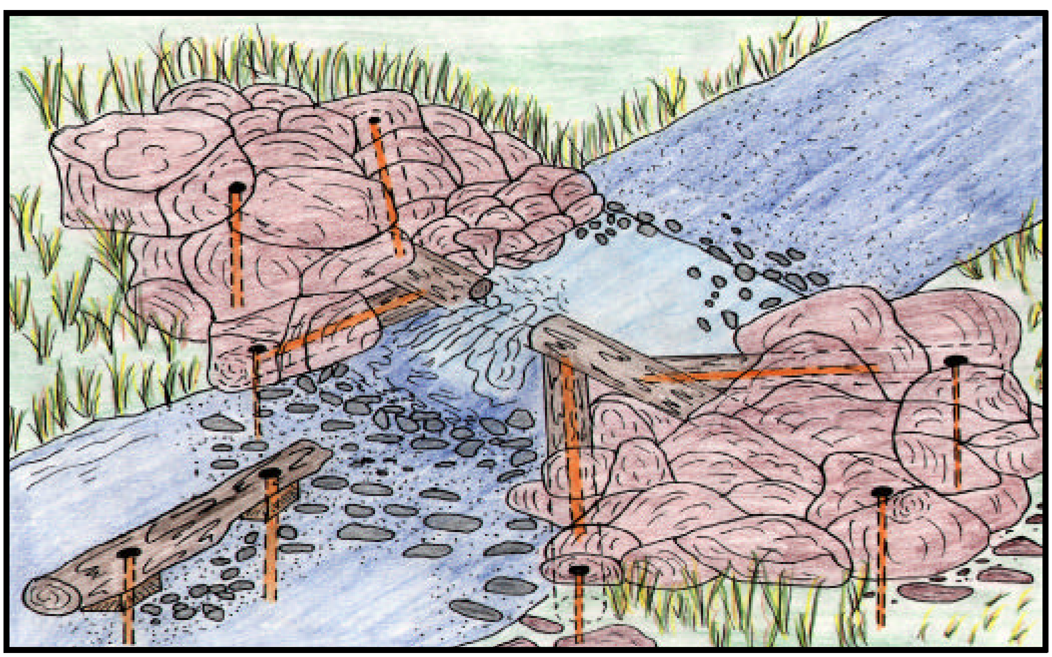
K-DAM.

(Information extracted from "Trout Stream Therapy.")

The K-dam creates a midchannel scour pool below the structure. The pool will be created below the main notched cross-channel log and also beneath the downstream extension of the streambank logs which display the K design. The K Dam works best in high gradient streams and in straight reaches at breaks in the stream gradient.

The downstream log extensions, or brace logs, are attached to the main notched cross-channel log with rebar. Upstream log extensions are optional, but, if used, they should be extended well back into the stream bank at 45-degree angles from the main notched cross-channel log. Armor the ends of the cross-channel log and brace logs with stones or riprap. From the cross-channel log, attach, roll out and bury roadbase fiber mat or wire mesh and cover with hardware cloth. The matting should be covered with substrate to prevent undercutting of the cross-channel log and to restore the natural bottom contour upstream of the sill. The K-dam is illustrated in Figure 43 along with a whole log cover.

After a few high-flow events, the scour pools will become evident below the cross-channel log and the downstream brace logs. If these events are far and few between, initial depth and dimensions can be excavated.



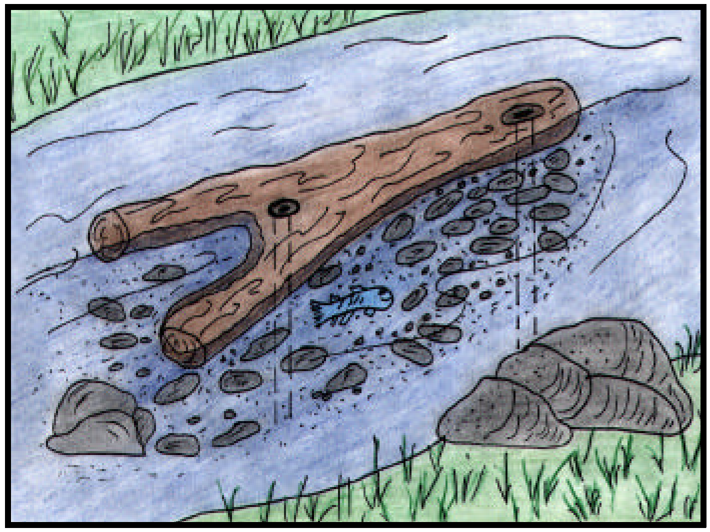
K-Dam and Whole Log Cover **Figure 43**

adapted from "Trout Stream Therapy"

WHOLE LOG COVER.

(Information extracted from "Trout Stream Therapy.")

A whole log cover, as illustrated in Figure 44, is used to provide resting and security cover for trout. This natural type structure is nailed, by rebar, in the middle of the stream or immediately adjacent to the main streamflow. The log should be positioned over a gravel streambed where the water is deep enough to cover the log during normal flow. Placement of these logs can be in combination with other structures.

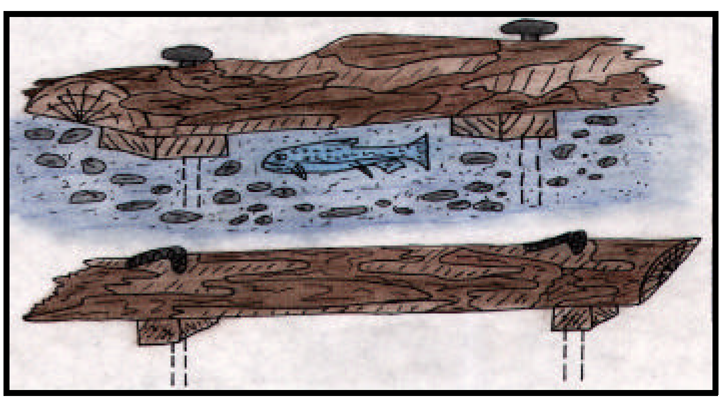


Whole Log Cover **Figure 44**
adapted from "Trout Stream Therapy"

HALF LOGS AND SLAB LOGS.

(Information extracted from "Trout Stream Therapy" and "Applied River Morphology.")

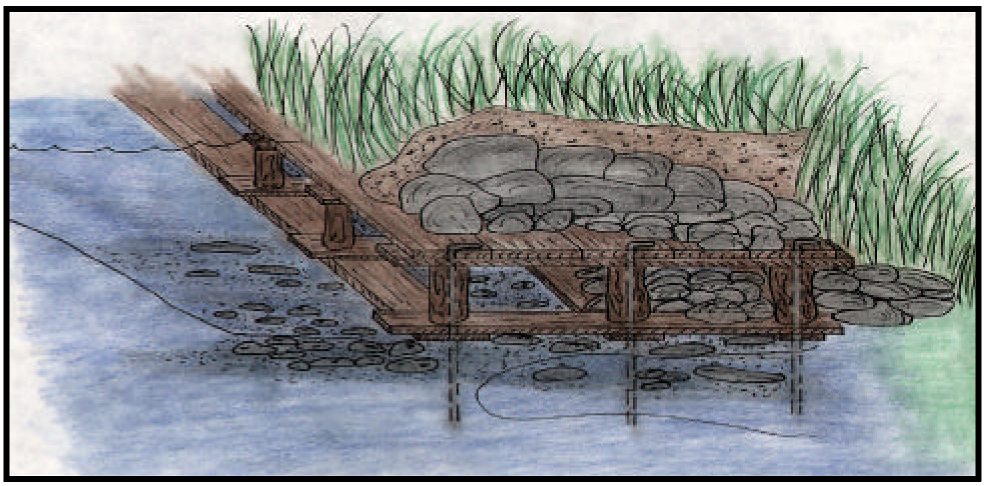
Half logs and slab logs provide resting and habitat cover as well as a natural looking structures for trout in areas where in-stream cover is limited. The most common material used for half logs is green-cut oak. The half-logs should be 8-10 feet long and at least one (1) foot in width. One-half inch holes are drilled near the ends of each half-log, so 1/2-inch rebar, six (6) feet in length can fit through the half logs. Two (2) spacer blocks, which will rest on the stream bottom, at six (6) inch square with 1/2-inch holes centered drilled, will fit underneath the half logs. The half logs are to be positioned almost parallel with the stream flow, so that low velocity flow is provided under the log. Make sure that half the log is completely underwater and drive the rebar into the stream bottom till about six (6) inches jut over the half log. Bend these rebar ends over the half log in the downstream direction. Slab logs can also be used in this same manner. This is a nice modification when in areas of shallower stream channels. Half log and slab log are illustrated in Figure 45.



Half Log and Slab Log **Figure 45**
adapted from "Trout Stream Therapy"

LUNKER STRUCTURE.
(Information extracted from "Trout Stream Therapy.")

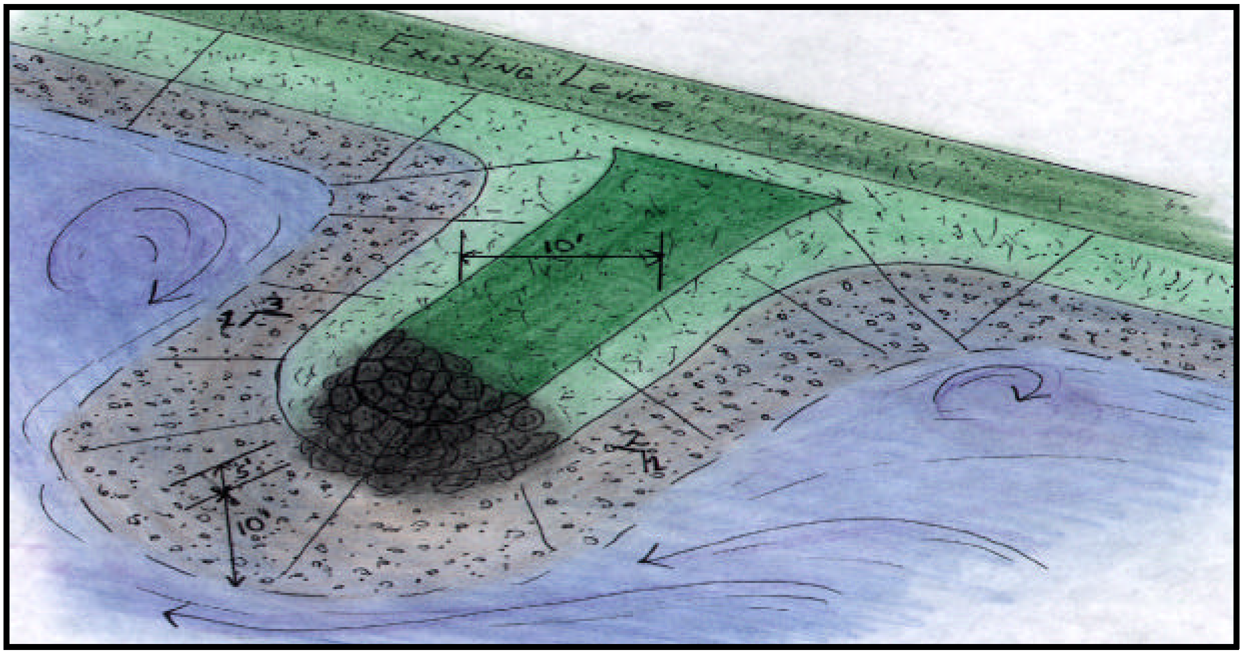
The lunker structure is designed specifically to increase the combination of pool and overhead cover habitat and is usually built in high gradient streams. This structure is also used as a streambank cover and a current deflector. The stream bottoms should have extensive reaches of cobble and rubble substrate. The lunker is a prefabricated, sandwich-like, wooden platform structure that rests directly on the stream bottom, as shown in Figure 46. Each layer is made from two (2)- to three (3)-inch green-cut planks (e.g., oak) with an eight (8) to ten (10)-inch space between the sandwich layer. This space can be sections of three stubs. Several rebars which are driven directly into the stream bottom, anchor the structure in place.


Lunker Structure **Figure 46**
adapted from "Trout Stream Therapy"

Lunker structures are installed in a continuous sequence along the current-bearing bends of the stream. If stream meanders are limited, additional structure-based bends should be created. If necessary, at normal flow, excavate some of the stream bottom or substrate in order to submerge each platform completely. Wing deflectors and weirs are often used in conjunction with lunker structures to direct and manipulate flow levels. Large stones or riprap should be placed along the stream side edge of the platforms for stability. Use smaller stones and dirt behind the larger stones to fill in the voids. The eroded stream bank reaches will need to be sloped back and contoured to tie in with the back of the lunker structure. Use a mix of grass seed or sod on top of the lunker structure as well as other areas where construction took place. Also vegetate the exposed slope by using plantings and where the slopes are more heavily stressed apply brush matting, fascines, etc. After a season or two, the vegetation should have grown providing restoration along with needed erosion-resistant conditions. Lunker structures are not recommended for streams subject to severe flooding. Choose hardwood logs and rough cut lumber from local sources as well as rock for riprap toe. Heavy equipment may be necessary for excavating and installing the materials.

ROCK AND WOOD SPUR DIKES.
(Information extracted from USACE Walla Walla District.)

Rock Spur Dikes. Rock spur dikes are constructed as short extensions of a dike on the order of 15 to 50 feet in length, which extend into the river to cause irregularities in the bank and adjacent river flow. Rock spur dikes may be placed along levees in groups to enhance protection of the levee. Large boulders or riprap would provide relatively permanent structures and protect banks and islands from erosion for many years. Wood piling or rock placed on a shallow foundation would be prone to wear with time and eventually be naturally eliminated. Figure 47 illustrates a rock spur dike.



Rock Spur Dike **Figure 47**
adapted from Walla Walla District USACE

Wood Spur Dikes. Wood spur dikes would provide the same values and functions as rock spur dikes but at a much lesser cost. Treated timbers environmentally approved for in-water use, or cedar or other natural woods resistant to decay, could be driven into the river bottom to serve as an energy dissipator. Heavy rock or river cobbles placed downstream of the fence would discourage normal scour at the base of the fence.

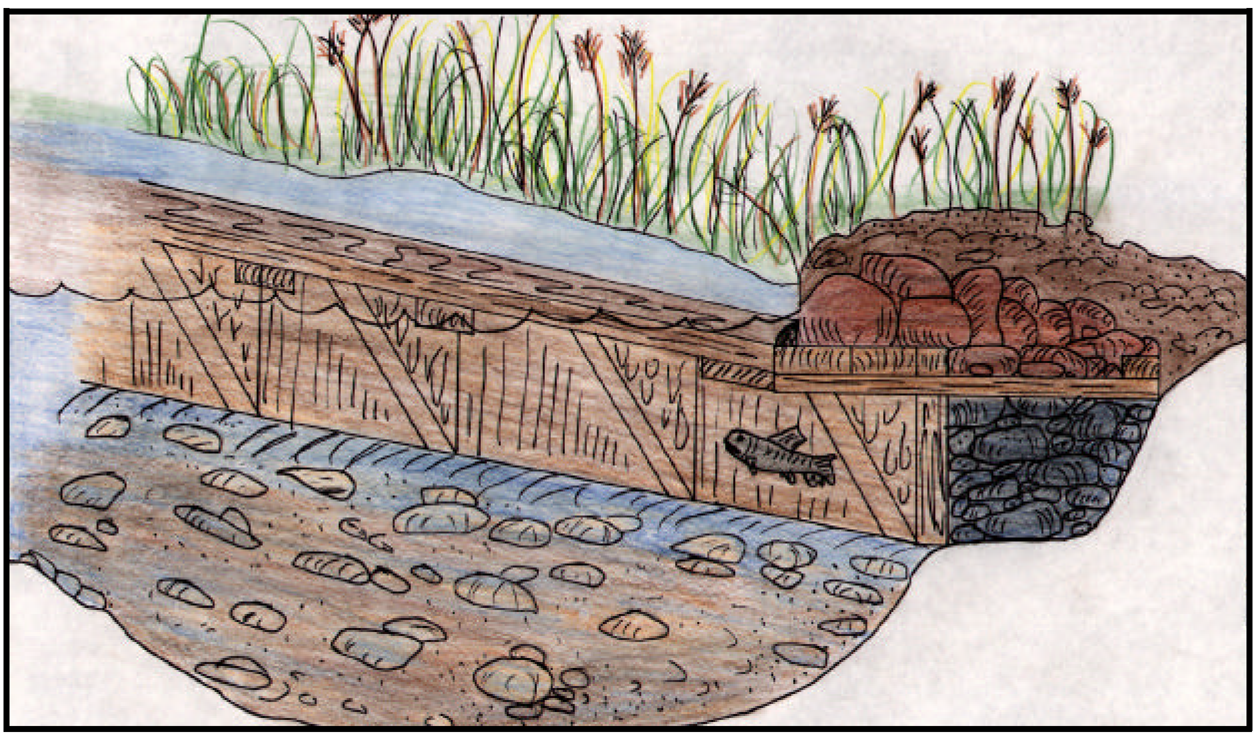
Spur dikes have the potential to replace lost pool habitat and increase the physical complexity of the shoreline.

SKY-HOOK BANK COVER.

(Information extracted from "Trout Stream Therapy.")

The sky-hook bank cover, illustrated in Figure 50, is a prefabricated structure used as a bank cover and current deflector. It greatly increases the amount of pool area and habitat cover as shown in Figure 48. It is best used in low or moderate stream gradients and in shallow stream channels that are excessively wide with erosion-resistant substrates and low-profile stream banks.

Within the boundaries of the shallow stream channel, mechanized equipment is used to excavate a narrower, deeper meandered channel. Along the outside curves of the excavated channel, the prefabricated sky-hook bank cover structures are positioned so that the platforms are cantilevered two (2) to 2.5 feet over the excavated trench. On the back half of the platforms, use the material that was excavated for the trench and fill to provide counterweight. Larger stones are to be placed along the front edge of the platform, using something similar to a quarter round to hold back the material. Complete the top of the platform with sod and/or native vegetation plantings or seeds.

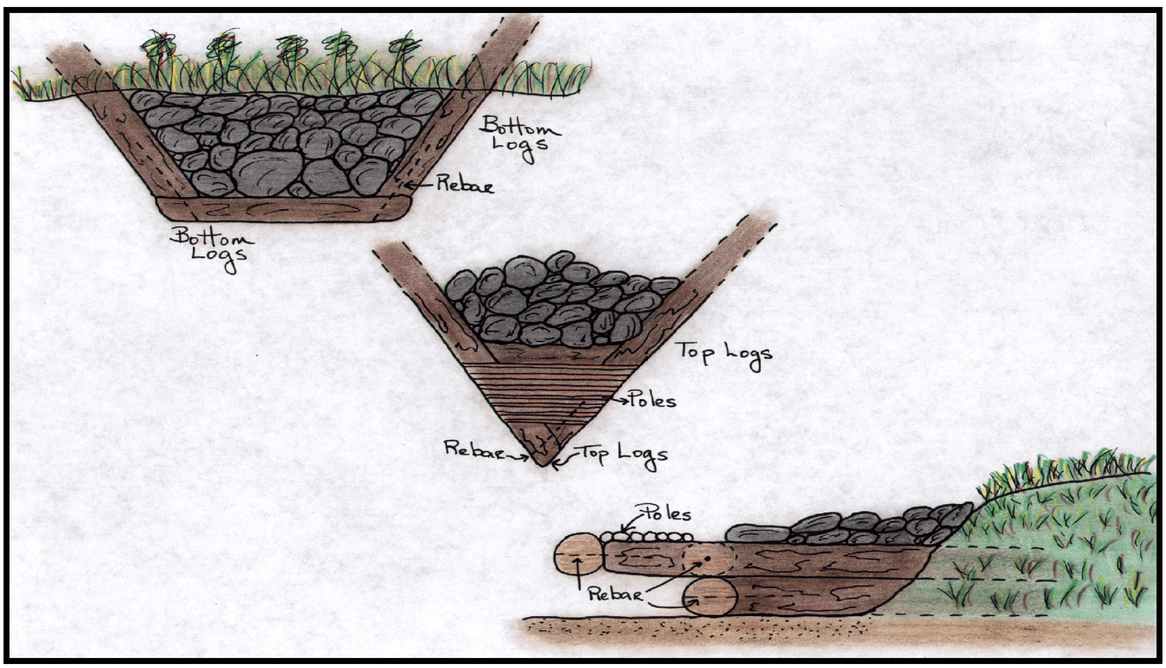


Sky-Hook Bank Cover **Figure 48**

adapted from "Trout Stream Therapy"

TIP DEFLECTOR.
(Information obtained from the USDA's Forest Service.)

The tip deflector is a variation of the single-wing deflector which is designed to provide maximum overhead cover. This structure is two (2) logs high, with the upper logs extending two (2) to four (4) feet past the bottom logs, thus creating a shelf effect as shown in Figure 49. Note the illustration is shown in sections (aerial views of the bottom and top logs and side view of complete structure.) It can be placed alone or in pairs. This structure is most suitable in low gradient sections 15 feet or more in width. Properly installed, tip deflectors can create the maximum amount of overhead cover. Installation is considerably more expensive than for the single-wing deflector, and suitable sites are limited by bank height. One (1) pair of tip deflectors can be installed per crew day on streams 15 to 20 feet wide.



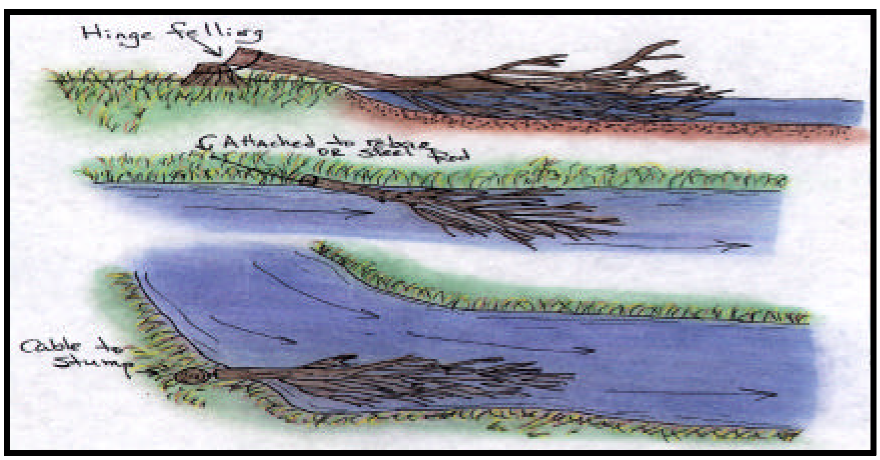
Tip Deflector **Figure 49**
adapted from the Forest Service

TREE COVER.
(*Information obtained from the USDA's Forest Service and extracted from "Streambank Corridor Restoration Handbook."*)

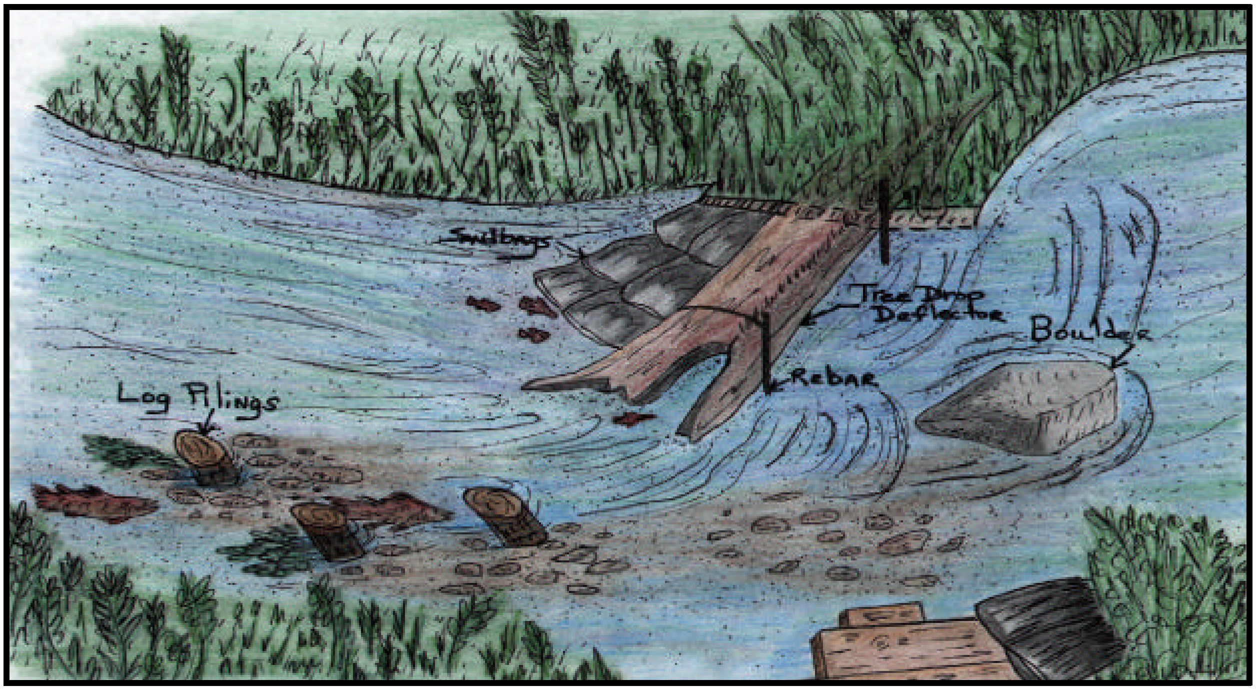
Trees placed and/or felled in proper locations can provide several benefits. They provide excellent overhead cover and an ideal substrate for aquatic organisms. In addition, trees serve as deflectors to constrict wide, shallow channels, thus increasing stream velocity, deposition, bed material sorting, drift catchment and creating deeper water or scouring. Trees or shrubs can be placed in any section of stream large enough that the installation would not create serious bank erosion due to flanking. The greatest benefits are probably realized in wide, shallow streams with sand or gravel substrate.

Trees can provide excellent benefits with low installation costs. In larger streams with unstable substrate and no means of attaching cover logs, trees may be the only likely alternative. Small channels may preclude the use of trees. Channels must be large enough to accommodate trees without threatening bank erosion and limiting needed channel flow capacity. Suitable trees may not always be available in the immediate vicinity. Tree covers generally require frequent maintenance; particularly where ice occurs.

Trees are normally cut in place and felled directly into the stream (in a downstream direction) with the axis at a 20- to 30-degree angle to the streambank as shown in Figure 50. If the tree is located properly, it can simply be hinge-felled in place. If not, it can be cut, placed, and then attached with cable to the stump or a six (6)-foot rod driven into the ground. In smaller streams, understory shrubbery, such as rhododendron, can be used in the same manner as trees. Where trees are hinge-felled, they should also be cabled to the stump to insure stability. Where equipment is available, whole trees including the root wad can be pulled and placed. Where trees are hinge-felled or dropped in place, an experienced crew of two (2) workers can cut and cable eight (8) to 12 trees per day. Where trees must be moved by heavy equipment, about four (4) to eight (8) trees per day can be accomplished.



Tree Cover **Figure 50**
adapted from the Forest Service



Tree Drop Deflector and Midchannel Deflectors **Figure 51**
adapted from "Trout Stream Therapy"

TREE-DROP DEFLECTOR AND OTHER MIDCHANNEL DEFLECTORS.
(Information extracted from "Trout Stream Therapy.")

Tree drop deflectors, as illustrated in Figure 51, present a natural type of construction in regards to stream deflectors and can be used in gradient independent streams. Select dead or dying tree portions near the stream edge and angle them in the downstream direction. The butt end of the tree should be anchored to the stream bank on the inside bend with either cable or rebar. Sandbags are placed on the upstream side of the tree trunk to prevent undercutting. Sandbags are also positioned on top of the tree trunk so sod and/or native vegetation can be planted.

Other types of midchannel deflectors include log pilings, see Figure 51. If substrate is easy to excavate, log pilings can serve as deflectors and also as feeding areas for fish. Log pilings are angled somewhat in the downstream direction and driven deep enough so the entire piling is completely underwater. One other type of midchannel deflectors are large boulders, see Figure 51. Using mechanized equipment, boulders can be placed at critical points along the stream channel. Boulders also create feeding areas as well as scour holes or pools around the boulder.

VORTEX ROCK WEIR WITH FLOATING LOGS.

(Information extracted from "Applied River Morphology.")

The vortex rock weir is a channel stability/habitat improvement structure. This structure was designed to offset the adverse effects of straight weirs and check dams, which create backwater and flat slopes. It was also designed to avoid the problems of the downstream pointing weirs which create twin parallel bars and a scour hole which de-stabilizes the structure. The objectives of this structure are to: 1) create instream cover/holding water; 2) take excess shear stress away from the "near bank" region and direct it to the center of the stream to maintain lateral stability; 3) increase stream depth by decreasing width/depth ratio; 4) increase sediment transport capacity; 5) provide a natural sorting of gravel (where naturally available) on the up-welling portion of the downstream side of structure for spawning beds; and 6) create grade control to prevent down cutting.

Modification of this design includes floating, anchored, overhead log/root-wad covers. It is illustrated in Figure 52. The objectives of this modification are to: 1) protect the streambank from erosion; 2) provide in-stream and overhead cover for fish; 3) provide shade, detritus, and terrestrial insect habitat; 4) look natural; and 5) provide diversity of habitats.

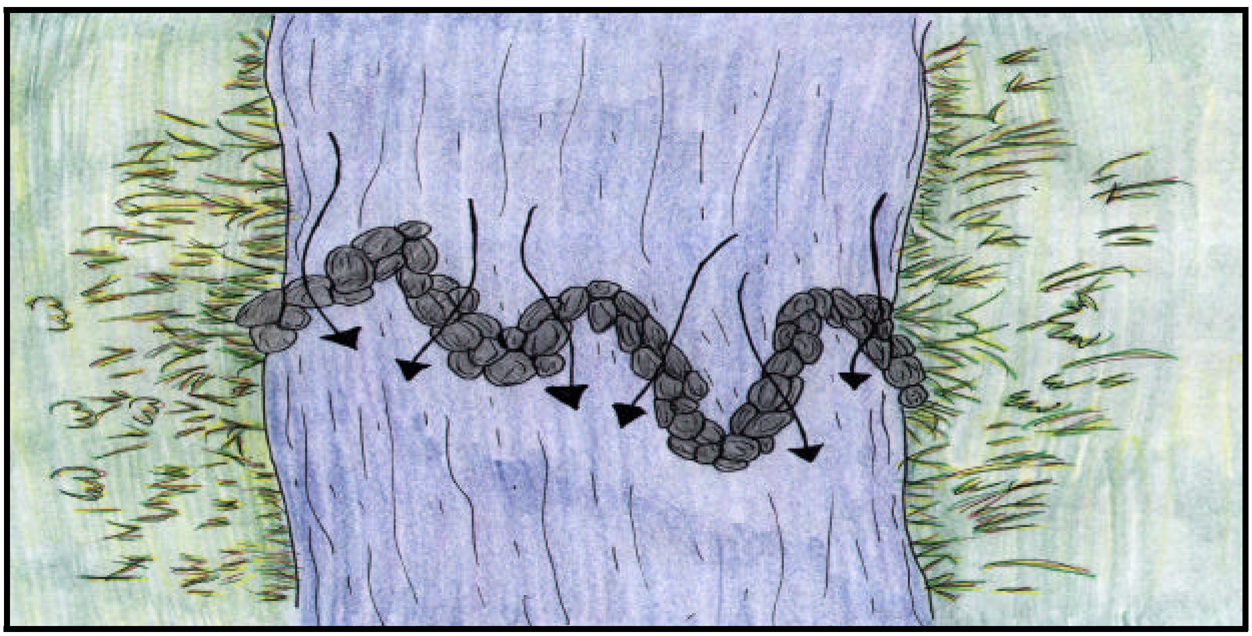
Vortex Rock Weir with Floating Logs **Figure 52**

adapted from "Applied River Morphology"

"W" ROCK WEIR.

(Information extracted from "Applied River Morphology.")

This channel stability/habitat improvement structure, this structure is designed for river widths generally greater than 40 feet. See Figure 53. This boulder structure is designed to create in-stream cover and diversity of velocity and depth and more useable area across the channel width. It looks much more natural than straight or curved weirs on wider channels.



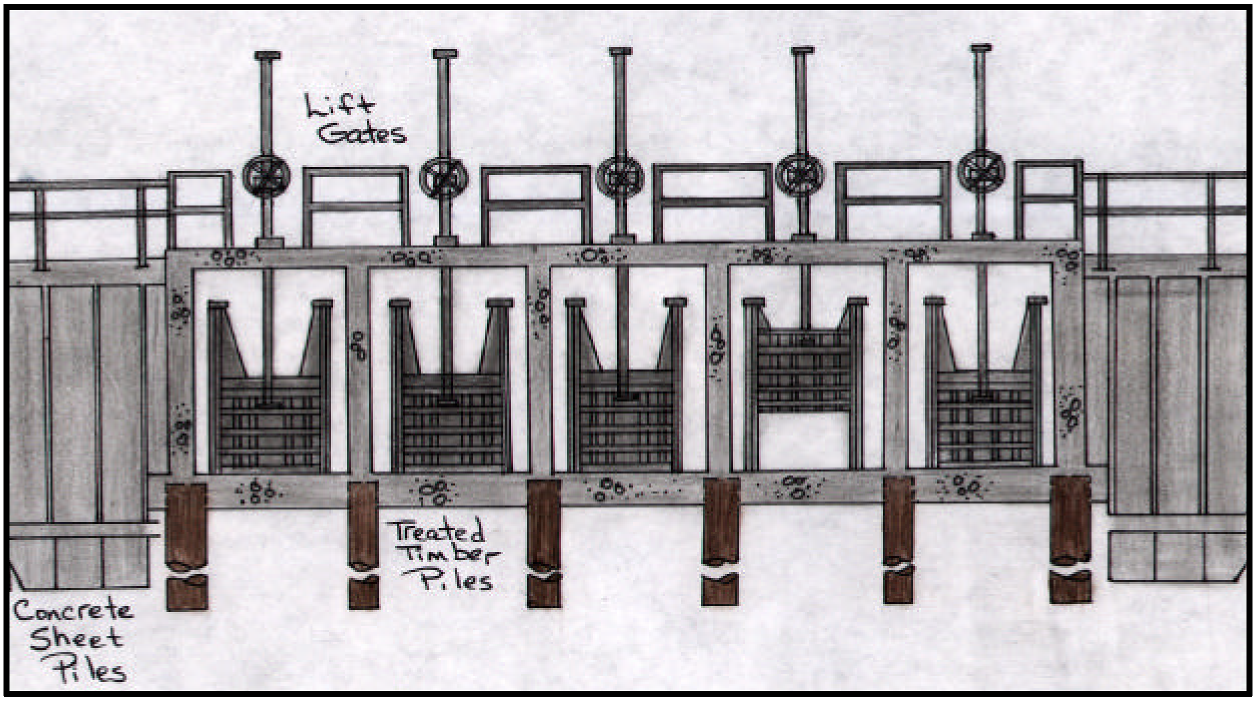
"W" Rock Weir **Figure 53**

adapted from Applied River Morphology

WATER CONTROL STRUCTURE.

(Information adapted from the USACE's Galveston District.)

Figure 54 illustrates a type of a water control structure. This particular water control structure is located on the McFadden Ranch Wetlands, Texas which was constructed by the Galveston District U.S. Army Corps of Engineers. The area is located just southwest of Port Arthur, Texas, and just south of the Gulf Intracoastal Waterway (GIWW) and just west of the Sabine-Neches Waterway. The objective of this project was to reduce saltwater intrusion from the GIWW into a historically fresh to slightly brackish marsh.



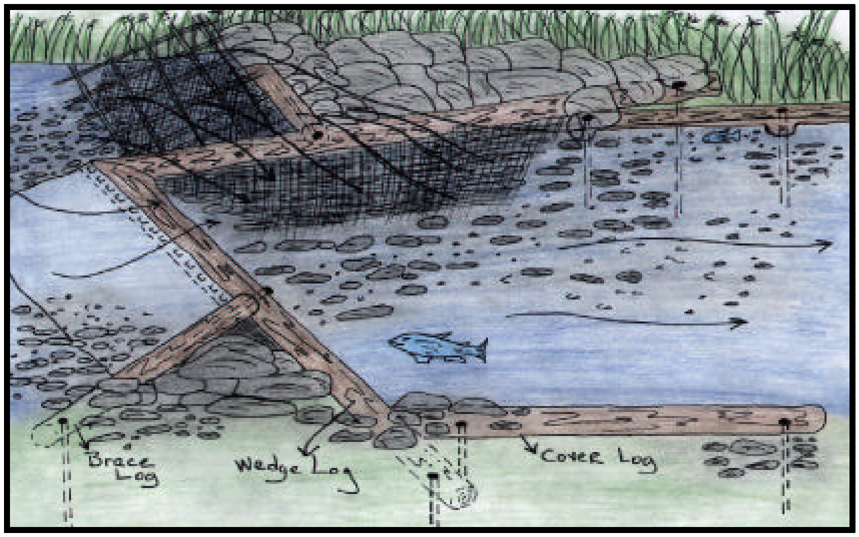
Water Control Structure **Figure 54**
adapted from USACE - Galveston District

The water control structure consists of five (5) gated culverts. Each of the gated culverts are equipped with a sluice gate on the marsh side and a flap gate on the GIWW side. The sluice gates will be operated using a portable drive unit. An intake channel was excavated between the existing bayou and the new structure as well as an outlet channel between the new structure and the GIWW. With the material from the excavation for the new structure and channel and from new cut dredged material, a dam was constructed on the existing outlet channel. A boat roller system was installed adjacent to the new structure. Stone riprap was installed at the water control structure along the new channel, and training levees were constructed on both sides of the new structure and along the GIWW.

WEDGE DAM.

(Information extracted from "Trout Stream Therapy.")

The wedge dam is used in high gradient streams to direct flow toward the center of the stream to create a plunge pool below the wedge. See Figure 55. The two (2) wedge logs should be joined at 45 degrees at the center of the stream with rebar. The butt ends of these logs, pinned down with rebar, should be a few inches higher than the apex junction so flow will concentrate in the center of the plunge pool during normal and low flow intervals. A roadbase fiber mat or a mesh/hardware cloth combination is to be attached to the two (2) wedge logs. Roll out the mat or mesh/hardware cloth combination and bury it with substrate to prevent undercutting the two (2) wedge logs. Make sure the height of the wedge is sufficient to create a turbulent bump during normal flow to help maintain a scouring action in the plunge pool. The brace logs should be at a 90-degree angle to the upstream side of the wedge logs and extend well back into the stream bank trenches, also pinned with rebar. The brace logs and the ends of the wedge logs are to be covered with stones or riprap. Again, the plunge pool can be initially created after construction, but long-term dimensions will rely on erosive forces during high-flow periods.



Wedge Dam **Figure 55**

adapted from "Trout Stream Therapy"

LOW STAGE CHECK DAM & MEDIUM STAGE CHECK DAM.

(Information extracted from "Applied River Morphology.")

Similar to a wedge dam, the low stage check dam is one of the most common devices installed for fish habitat improvement. Low stage check dams are dams that are placed low in the channel profile (generally less than 1/3 of the bankfull stage). They are appropriately termed a plunge or ledge, rather than a dam, because of their low height. These devices are not designed for pool formation above the structure, but rather to form a plunge pool below. Low stage dams are normally placed in long shallow riffles on straight reaches and meanders. The medium stage check dam is another type of check dam which is placed higher in the channel profile (up to 3/4 bankfull).

NESTING.

EARTH FILLED CONCRETE CULVERTS FOR WATERFOWL NESTING AND ISLANDS FOR NESTING WATERFOWL (PRAIRIE POTHOLE REGION).

(Information extracted from the Northern Prairie Science Center and the USACE's St. Paul District.)

Earth Filled Concrete Culverts. Earth filled concrete culverts, Figure 56, have proven to enhance waterfowl production. These nesting type sites attract mallards as well as Canada geese, and have been successful at least in Montana and North Dakota. Once properly installed and filled, these type of structures require little maintenance. They have proven to be reptilian and mammalian proof.

For the best results, concrete culverts should be placed in areas with good mallard populations, low duck nest success, and minimal competing upland nesting cover, but they can be placed in other areas. The following criteria (St. Paul District) should be considered when examining areas for installation:

Nesting Structure (Culvert) **Figure 56**
USACE St. Paul District
Photo taken by Tim Bertschi

- Culverts should be targeted to Type IV wetlands, followed by larger Type III's and sheltered areas of Type V's. Culverts resist, but are not immune to ice action.

- Best sites are within six (6) feet of emergent vegetation in about 18 inches of water.

- Avoid areas with nearby trees which provide hunting perches for raptors and crows.

- It is difficult to provide guidelines for the number of culverts to be placed in a single wetland or in an area. In general, try not to put out more culverts than the number of mallard pairs available to use them within a one (1) mile radius. Never more than one (1) per wetland acre; one (1) to 10 or 20 acres is a more realistic goal for starters. Choose the best sites and also consider that geese will likely use many of them.

These culverts should be handled carefully as there are possibilities of cracking or collapsing. They should be stored, carried and handled in an upright position. Storage should be on wooden blocks to prevent the culverts from freezing to the ground. When transporting the culverts to installation sites, they are not to be rolled or dropped off the truck, but to be lifted using at least an eight (8) foot chain which attaches to lifting rings inside the culvert. Unloading can be accomplished by using a "farm-hand" type loader capable of safely lifting 1,400 pounds.

It is preferable to install the culverts when wetlands are dry. Installation is as follows:

- Scrape a depression in the wetland bottom with a loader bucket;

- Place the culvert in the depression;

- Push down and square the culvert with the bucket;

- Fill the culvert with soil from the wetland bottom to overflowing to accommodate for settling.

Installing the culverts through ice is possible, but it is much more difficult and hazardous. Keep in mind that the ice must be strong enough to support heavy equipment, personnel and the culvert, as the bottom mud may have not yet frozen. Installation through ice is as follows:

- Cut a hole in the ice at the selected location using an ice auger, chain saw, spud, or combination;

- Cut a circle of ice with a hole in the middle so the ice chunk can be lifted clear;

- Lift the culvert into the hole, push down into the mud and level;

- Fill the culvert with soil.

The following is important information regarding the soil, filling and cover:

- Fill the culvert with soil suitable for plant growth.

- Don't fill the culverts with soil containing alkali or salt.

- Don't fill with rock or gravel, as moisture will not reach vegetation. A mixture of rock or gravel with the soil can work.

- Use good quality soil.

- Remember soil settles and culverts need to be checked to replenish soil. Once settling has stopped, no additional maintenance should be required.

- Spread seed into the soil.

- Straw and grass can be mixed into the soil to provide a seed source.

- Weed cover is generally acceptable.

- Flax straw can be installed to provide a vertical and horizontal nesting cover for the first year, as mallards will not nest in bare soil.

Islands for Nesting Waterfowl (Prairie Pothole Region). In this region, most waterfowl species nest on islands. The open beaches on islands in the prairie pothole region are favored nesting habitats for shorebirds. Constructed nesting islands are of two general varieties: 1) standard islands and 2) rock islands. The standard islands are made of earthen mounds, usually larger than 0.1 acre. These are built mainly with draglines, bulldozers and scrapers. See Figure 57. Rock islands are smaller than standard islands, usually less than 0.01 acre. Rock islands provide a different function than standard islands as they are built mainly in less than 0.1 acre and are built mainly in small, seasonal wetlands.

Island Construction Area & Nesting Structure Figure 57
USACE St. Paul District
Photo taken by Tim Bertschi

The most successful standard nesting islands are farther from shore (400 to 1,500 feet) where they are less susceptible to mammalian predators. Islands farther than 1,500 feet may be harmful to ducklings hatched on the islands as they must cross long stretches of open water, and could be lost to predators or turbulent wave action. Also, islands that are placed away from emergent vegetation are safer nesting habitats than islands near emergent vegetation. The emergent vegetation provides cover and access routes for predators.

Nesting islands must be within one (1) mile of a complex of wetlands for sustenance to waterfowl breeding pairs and broods. These wetland complexes should contain both seasonal and semipermanent ponds to provide important food and cover for nesting hens and broods.

Earthen nesting islands should be built in an oval, kidney or peanut shape with rounded outlines rather than square corners. The erosive effects of waves can be reduced when the point of the island is directed into the prevailing storm winds that occur during the ice-free months. Riprapping the edge of the island may be necessary in open water to prevent erosion. To minimize cost, islands should be constructed where the water depth seldom exceeds three (3) feet. In open water habitat, Ducks Unlimited recommends that the island base be as high as the average water level in the wetland and constructed with 10H:1V side slopes and the top of each island should rise four (4) feet above the base and have 4H:1V side slopes. A 10-foot-wide, flat berm is usually constructed between the bottom of the island slope and top edge of the base slope to absorb wave energy to slow island erosion. For islands built in wetlands with moderate wave action, a single 6H:1V or 8H:1V side slope with a berm is acceptable.

The island should be constructed with soil or fill from the wetland bottom immediately adjacent to the construction site or from an upland borrow area. During construction, fill material should be deposited in a continuous, layering fashion. Each layer of material must be thoroughly compacted before another layer is put into place. Four (4) to six (6) inches of topsoil should be spread across the surface of the island. Grass seedings should be planted as soon as construction is completed. Low shrubs should be planted after the threat of frost has passed. Constructed earthen mound islands provide excellent predator-free nest sites, but they are expensive to build.

Rock islands are usually placed in seasonal wetlands, often close to the shore, within stands of emergent vegetation and function like large nest structures. These have been successful because they are safeguarded from upland predators by water barriers yet they are too small to attract aquatic predators such as mink.

No more than one (1) rock island should be placed in each 20 acres of wetland habitat. No more than 20 should be built in one (1) square mile of prairie-pothole habitat.

Rock islands should be constructed when wetlands are sufficiently dry to support heavy equipment. These islands are built primarily of rock piled in a wetland basin to a height of two (2) to three (3) feet above the average water level. Another two (2) to three (3) feet of soil from the marsh bottom or adjacent upland sites is placed on top of the rocks. The completed rock islands are only 10 to 15 feet in diameter. Seeding should be accomplished soon after construction is completed.

Islands have several advantages over other nest structures; they can be used by several pairs of nesting geese as well as nesting ducks, make good lodging and feeding sites, provide habitat for other wildlife, require little maintenance, and are long-lived when properly constructed. Their main disadvantage is that initial costs can be high.

ROUND HAY BALES AS NESTING STRUCTURES.

(Information obtained from Northern Prairie Science Center.)

Round hay bales, turned on end, make attractive nest sites for ducks and geese. The advantages to round hay bales are:

- Bales are readily available;
- Do not require construction;
- Often inexpensive;
- Provide loafing sites and habitat for other wildlife; and
- Biodegradable.

The disadvantages include:

- Difficult to place in ponds;
- Cannot be used where water levels fluctuate excessively: and
- Usually need to be replaced every two (2) to three (3) years.

Flax straw is the best material for nest bales because it is coarse and resistant to rotting. If not available, a coarse grass hay is a good substitute.

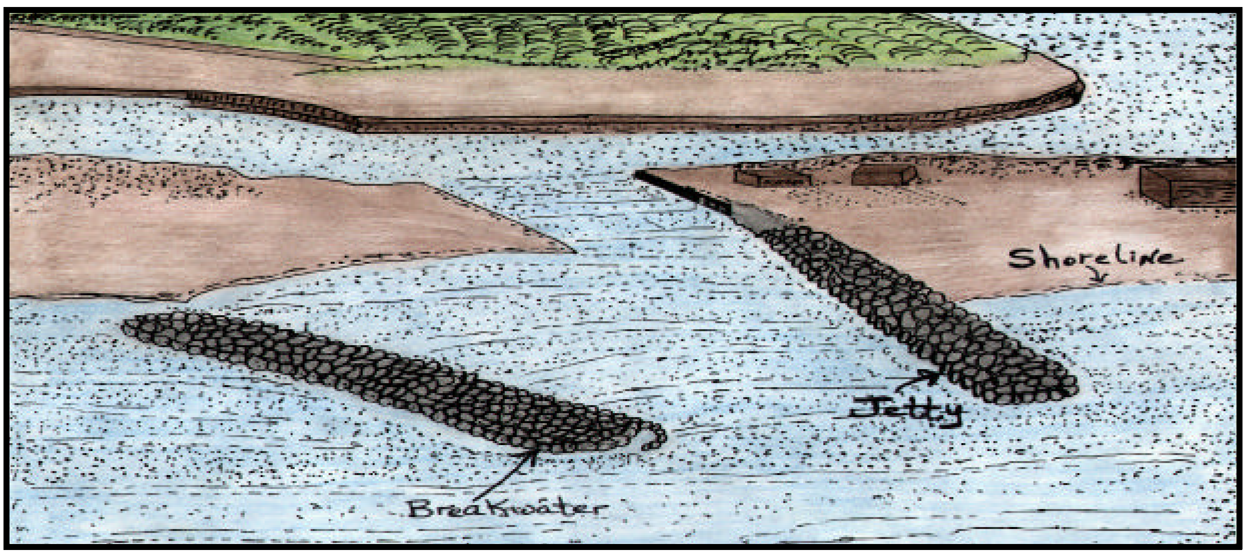
Round Hay Bales **Figure 58**
obtained from North Prairie Science Center

Where ice is adequately thick, it is possible to roll the bales out by hand or use a tractor for placement. To insure bales do not tip over when the ice thaws, they should be placed on end in a large hole cut in the ice. Bales should be placed at least 50 feet from shore in 18 to 30 inches of water when possible. Initially, bales should be placed 150 to 300 feet apart with no more than one (1) every one (1) to two (2) acres. Figure 58 illustrates round hay bales.

BREAKWATERS AND JETTIES.

(Information extracted from EPA's Office of Wetlands, Oceans and Watersheds and Corps of Engineers' Waterways Experiment Station.)

Breakwaters. Breakwaters are wave energy barriers designed to protect the land or near shore area behind them from the direct attack of waves. Breakwaters have traditionally been used only for harbor protection and navigational purposes; but in recent years, designs of shore-parallel segmented breakwaters have been used for shore protection purposes, see Figure 59. Segmented breakwaters can be used to provide protection over longer sections of shoreline than is generally managed through the use of bulkheads or revetments. Wave energy is able to pass through the breakwater gaps, allowing for the maintenance of some level of longshore sediment transport, as well as mixing and flushing of the sheltered waters behind the structures.



Breakwater and Jetty **Figure 59**

The dissipation of wave energy allows drift material to be deposited behind the breakwater. This accumulation of material protects the shore and may also extend the beach. The amount of deposition depends on the site characteristics and the design of the breakwater. Breakwaters may be either fixed or floating. The choice depends on the normal water depth and the tidal range.

Fixed Breakwaters. Fixed breakwaters are most economical when the slope is gentle and the high water level at the proposed site is less than about four (4) feet deep. If the water at high tide is deeper than four (4) feet, the fixed breakwater would need to be built so high that its cost would be prohibitive. Floating breakwaters can adjust to higher tides, but they are effective only against waves of short length. If these conditions do not match your site, you might consider an alternative structure such as a revetment, bulkhead, or groin field which are discussed in this handbook.

The nature of the bottom material is also important. Stone rubble or sandbag breakwaters can rest on any type of bottom, but they may settle if placed on soft earth or sand. A filter layer between the structure and the bottom can relieve this problem. Special attention should also be paid to the anchors that hold floating breakwaters in place in soft bottom locations. While sheet piles can only be driven or jetted into relatively soft bottoms, scouring and tipping may create problems in areas where bottom material is very soft.

The degree of protection desired from a breakwater must be carefully considered. If the breakwater is too high, it will seriously interfere with shoreline processes; too low, and the shore will be inadequately protected.

The height and porosity of a fixed breakwater determines the extent to which drift will be deposited behind the structure. It is generally desirable to allow some of the wave action to pass over or through the breakwater, because many people value the waves as part of the natural beauty of the shore and as an essential ingredient in their recreational experience. This wave energy also helps to keep the area between the breakwater and the shore from becoming overfilled with littoral drift. Breakwaters that are too porous are ineffective, however.

The material that fills in behind the breakwater might otherwise be deposited on someone else's beach, which may erode due to the breakwater. If this is likely, beach fill can be added between the shore and the breakwater until the rate of longshore transport resumes an acceptable level.

Like other vertical shoreline erosion control structures, fixed breakwaters are subject to scour or erosion at the base of the structure, or the "toe," where the resistant construction material meet the erodible beach bottom. Extra width at the base of a stone rubble breakwater or a protective rubble apron along the toe of a sheet-piling breakwater can help prevent this erosion and keep the structure from tipping.

Because breakwaters are designed to receive much of the impact of incoming waves, they should be designed strong enough to remain in place during the usual local storms. Floating breakwaters must be firmly anchored to the bottom and adequately connected. They may be unsuitable where wave action is relatively heavy. Especially heavy or durable construction elements may be required for all breakwaters in areas where damage from vandalism is a problem.

Stone rubble is useful as a fixed breakwater material if it is available in the vicinity at a reasonably cost. Filter material between the stones and the bottom sand or earth can help prevent settling and deformation of the structure. The stone material should be arranged so that the smaller stones are in the interior of the structure, armored and retained by the larger stones.

Rubber tires on treated-timber piles may also be used for relatively low cost, effective fixed breakwaters where timber piles can be driven deep enough to ensure stability. Horizontal rope or timber crosspieces are needed to keep the tires from floating off the tops of the piles in high water.

Treated-timber sheet piling performs well when used for fixed breakwaters and is applicable wherever the bottom will permit driving or jetting the piling to sufficient depth.

Burlap bags filled with a sand cement mixture (lean concrete) is another low cost construction element. They are suitable only where the tidal range is moderate and the bottom slope is fairly flat. Filter material should be placed under the structure to prevent settling.

Fixed breakwaters can also be constructed with other materials that are only suitable in certain locations or require special installation or design adjustments. These materials include sandfilled bags, gabions, concrete boxes, and the patented Longard tube, Z-wall, Sandgrabber, and Surgebreaker concrete blocks. Patented systems are generally available only through franchised dealers and may require special equipment for installation, resulting in relatively higher initial costs.

Floating Breakwaters.

There are several types of floating breakwaters. Materials used for floating breakwaters include: wood, reinforced concrete, barges, scrap tires, logs, and steel drums.

Floating breakwaters can be built with tires bolted or tied together. The type and material of fasteners should be chosen in light of local conditions, the degree of up-and down-motion due to waves, and the flexibility that will be required as the completed structure rides on the water. The floating breakwater must also be anchored. The type of anchor depends on tide and bottom conditions; generally, piles remain in place longer than other anchors.

Jetties.

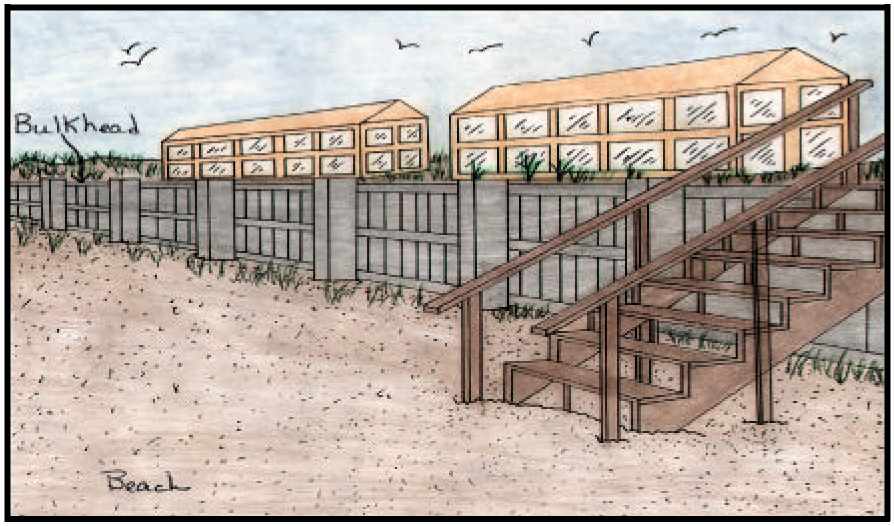
Jetties, as also shown in Figure 59, are long structures that are built perpendicular to the shoreline and extend out into the ocean. Their main objective is to keep sand from flowing into a navigation channel. There are often two (2) jetties used, one for each side of the navigation channel. Erosion prevention is another benefit of jetties. Sand that builds up against the jetty can be redistributed along the beach. Jetties also prevent littoral drift and storm waves from entering protected channels.

There are some disadvantages to jetties. Sand starvation and retreat of the shoreline on the downdrift side are possible. These problems are sometimes combated by sand bypass systems pumping sand through a pipeline and behind the downdrift jetty.

Jetties are constructed from various materials which include: stone, concrete, timber or steel.

BULKHEADS AND SEAWALLS.

(Information obtained from the EPA's Office of Wetlands, Oceans and Watersheds and the USACE.)



Bulkhead **Figure 60**

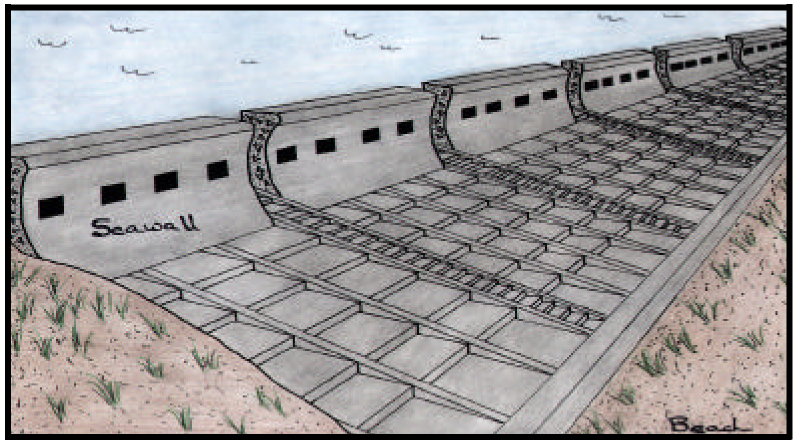
For sites where soil bioengineering marsh creation would not be an effective means of streambank or shoreline stabilization, a variety of engineering approaches can be considered. One approach involves the design and installation of fixed engineering structures. Bulkheads and seawalls are two (2) types of wave-resistant walls that are similar in design but slightly different in purpose. A bulkhead is a structure or partition placed on a bank or bluff to retain or prevent sliding of the land and to protect the inland area against damage from wave action as illustrated in Figure 60. Seawalls are principally structures designed to resist wave attack, but they also may retain some soil. A seawall is a structure separating land and water areas, primarily designed to prevent erosion and other damage due to wave action as illustrated in Figure 61. These structures **do not** protect the shore in front of them.

Both bulkheads and seawalls may be built of many materials, including steel, concrete, timber, or aluminum sheet pile, gabions, or rubble-mound structures. Design considerations for these types of structures are similar.

Bulkheads as well as seawalls can be built in three basic types of design. They may consist of thin interlocking sheet piles driven deeply into the ground; individual piles used to support an above-ground structure; or a massive gravity construction resting on the shore bottom or embedded slightly in it, supported by its own weight rather than by piling. Sheet piling is generally a slender, flat cross-section that is driven into the ground or bottom of a water body and meshed or interlocked with like members to form a wall or bulkhead.

Erodible bluffs where bulkheads and seawalls are appropriate, may rest on rocky, sand, or earth bottoms. The type of bottom influences the choice of bulkhead or seawall design, since none of the three (3) basic designs can be used for all shore bottom types.

With bottoms of sand and earth, interlocking sheet piles can be driven or jetted deeply. Designs using individuals piles to support above-ground structures can also be used in these areas. For sites with rocky bottoms, above-ground gravity structures are usually the most economical, but local wave energy or other considerations may make pile-supported structures the most appropriate choice. In soft rock, piles can be driven. Bedrock requires drilling holes for the piles and anchoring them firmly with grout or concrete.



Seawall **Figure 61**

Local wave energy also significantly influences bulkhead and seawall design. Because bulkheads and seawalls receive the full force of the waves, strength of materials is vital in areas where waves are especially heavy. Where the cost of materials needed to withstand extremely rough waves (reinforced concrete, for example) is prohibitive, a breakwater or combination of protective structures might be more suitable than a bulkhead or seawall.

Treated timber is generally the least expensive of the sturdy materials suitable for low cost seawalls and bulkheads, but it cannot be used in all designs. Timber is most useful in sheet-pile or in pile-and-plank designs. The combination of timber with steel H-piles is relatively more expensive, and its cost may limit this design to a small number of special applications.

Steel or aluminum may be used in sheet-pile form, the choice of material depending on cost and the nature of the shore bottom (steel can penetrate harder materials than aluminum). With all sheet-pile construction, however, special equipment is needed to drive the piles into the ground. The chief advantage of sheet piling in bulkhead and seawall construction is its neat appearance and relatively maintenance-free protection.

Bags filled with lean concrete mix and held in place by hogwire fencing are suitable for above-ground construction of gravity structures.

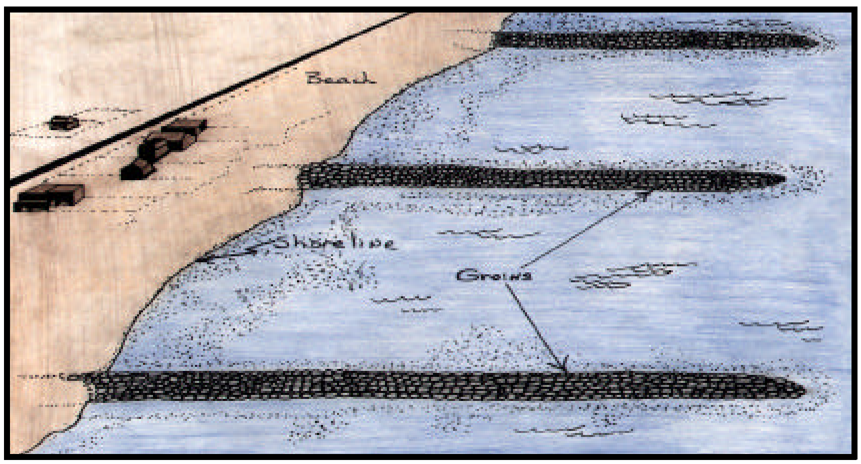
Care should be taken with all materials, both those that are locally abundant and those that are widely available, to conform to the design considerations mentioned earlier. In addition, special modifications may be necessary to adapt designs for use with locally available materials.

GROINS.

(Information obtained from the EPA's Office of Wetlands, Oceans and Watersheds and the USACE.)

Groins are structures that extend, finger like, perpendicularly from the shore. Usually constructed in groups called a groin field (as shown in Figure 62), their primary purpose is to trap and retain sand, nourishing the beach cells between them. Groins initially interrupt the longshore transport of littoral drift. They are most effective where longshore transport is predominantly in one direction, and where their action will not cause unacceptable erosion of the downdrift shore. When a well designed groin field fills to capacity with sand, longshore transport continues at about the same rate as before the groins were built, and a stable beach is maintained.

Groins are suitable erosion control measures where a beach is desirable, and they are compatible with most recreational activities. The beach fed by the sand trapped between the groins acts as a buffer between the incoming waves and the backshore and inland areas: the waves break on the beach and expend most of their energy there. Filled groins provide this protection during normal weather conditions but offer only limited protection against storm-driven waves. Groin fields must be carefully designed with respect to height, spacing, extension (both shoreward and into the water), and porosity.



Groins (Groin Fields) **Figure 62**

Spacing of groins depends on local wave energy and the amount of usual littoral drift. Groins should be spaced so that drift accumulates along the entire distance between the structures. If the groins are too far apart, part of each cell will be unprotected due to lack of accumulation; too close together, and not enough littoral material will accumulate in the cells. As a rule of thumb, groins should be spaced two (2) to three (3) groin lengths apart.

Groin design completely depends on conditions at the site. The structures are most effective in trapping sand when littoral drift is transported in a single direction. If there is no predominant direction of longshore transport, or if the littoral drift is clay or silt rather than sand, filling a groin field with sand from a nearby source may be necessary. Beach fill can also provide a beach sooner than natural action and help to minimize undesirable downdrift consequences.

The structures should be no higher than the level of a reasonable beach, so that when they are filled the sand is free to pass downdrift to neighboring beaches. Groins must be built to extend far enough into the water to retain adequate amounts of sand. However, they should not be so long that rip currents develop along them, carrying sand offshore into deep water where waves cannot return it to the beach. Excessively long groins can also aggravate erosion elsewhere by trapping sand that would have been deposited on the downdrift shore by uninterrupted longshore transport. Also, groins should be built to extend far enough inland that storm waves cannot bypass them on the shoreward side, undercutting the structure and eroding the beach.

As with bulkheads and revetments, the most durable materials used in the construction of groins are timber and stone. Less expensive techniques for building groins use sand- or concrete-filled bags or tires. It must be recognized that the use of lower-cost materials in the construction of bulkheads, revetments, or groins frequently results in less durability and reduced project life.

Sheet piles of treated timber, steel, or aluminum can be used to build effective and long-lasting groins in situations where they can be driven to adequate depth. Timber brace piles or mounds or rubble may be needed as reinforcement at the offshore end. Another way to use timber in groins is to drive posts into the bottom in pairs, with planks sandwiched between them. Because the planks cannot be embedded deeply when working under water, this method is limited to areas of wide tidal range where work can proceed during low tide. Where piles cannot be driven, a treated-timber framework lined with wire mesh and filled with rock can be used. This relatively light construction is suitable in moderate wave climates where the water is not deeper than about two (2) feet.

Rubble or quarrystone groins are sturdy but have high construction costs. The cost of rubble groins increases considerably with water depth. Either concrete rubble or quarrystone may be used, depending on local availability and cost. The smaller sizes should form the core of the structure, armored by larger pieces. Groins can also be built of stacked bags filled with sand or lean concrete. This material performs very well, but it may be more expensive than other types. Other materials that may be suitable in special cases are gabions (wire baskets filled with rock), Longard tubes, and steel fuel drums.

CHAPTER III. OTHER TECHNIQUES

This chapter describes other techniques that can be used for restoration purposes, but on a larger scale. Each of these techniques will entail broader activities than the engineering features described previously. Some of the techniques in this chapter do not have accompanying illustrations or photographs.

Fifteen techniques are described in this chapter. The first thirteen are categorized using similar categories as used in the "Streambank Corridor Restoration Handbook." The last two (2) techniques are categorized as present-day techniques.

BACKWATER MANAGEMENT.

SEDIMENT BASINS.

(Information extracted from "Streambank Corridor Restoration Handbook.")

Sediment basins are barriers or dams, often employed in conjunction with excavated pools, constructed across a drainage way or at other suitable locations to trap and store waterborne sediment and debris. The basins may be located off-stream and connected to the stream by a flow diversion channel, or may be an enlarged section within the channel. Sediment basins provide an interim means of reducing the sediment load from a stream. Unnaturally high amounts of sediment in a stream may lead to increased water temperature, decreased levels of dissolved oxygen, increased scour and erosion, and an inability for the system to support naturally occurring species. Sediment basins are used occasionally to sort sediment sizes.

Use sediment basins to temporarily reduce excessive sediment loads until the upstream watershed can be protected from accelerated erosion. They can also be used to separate out sediment which may be causing damages downstream along reaches which are incapable of transporting the sediment sizes. In urban areas, sediment basins may be integrated with more permanent storm water management ponds.

Sediment basins can only trap the upper range of particle sizes (sand and gravel). They allow finer particles (silt and clay) to pass through. Sediment basins fill in and require periodic emptying.

Develop plans for restoring the upstream watershed where excessive erosion is occurring. Integrate the sediment basin(s) with the upstream restoration plants as a means of protecting downstream areas until the watershed is restored.

Most states require minimum design standards for sediment basins and regulate those exceeding a certain size. Safety (risk from possible failure) must also be considered in planning and design.

Locate the sediment basin to obtain maximum storage benefit from the terrain in connection with considerations for minimizing environmental impact and ease of clean out. In urban areas, locate, if possible, where storm drains may outfall or be diverted into the basin.

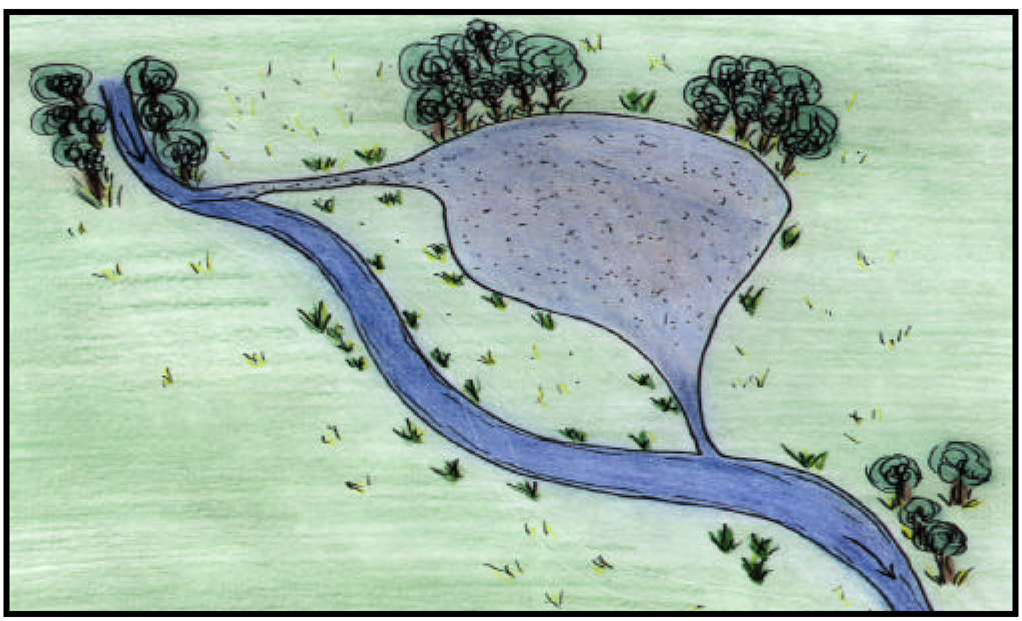
Provide for inflow protection to safely convey flow into the basin after periods of drawdown. Seek the assistance of professionals in the proportioning and location of any flow diversion structures, principal and emergency spillways, drawdown devices, sizing of embankments and excavations.

Develop an operation and maintenance plan and include identification of sediment disposal sites.

For temporary installations provide details for removing the sediment basin and associated appurtenances following stabilization of the sediment source.

Minimize disturbance to the stream and adjoining areas. Schedule the work between migrations and during periods when resulting disturbances will least interrupt aquatic biota. Divert flow around the work wherever possible.

Install according to detailed designs and construction drawings prepared for the site. Assure that fencing and signs are properly posted to warn the public of hazards involving soft sediment and floodwater. See Figure 63 for an illustration of a sediment basin.



Sediment Basin **Figure 63**

adapted from "Streambank Corridor Restoration Handbook"

WATER LEVEL CONTROL.

(Information extracted from "Streambank Corridor Restoration Handbook.")

Water level control involves the use of structures to maintain water levels within the channel and adjoining riparian zone. Water level control provides opportunities to create or restore aquatic habitat, control aquatic plants, and restore desired functions of adjoining wetlands.

Use water level control along reaches where flow depth in the stream, adjoining wetland or the interdependent saturation zone in the adjoining riparian area is insufficient to provide desired functions. This need will often vary by season and requires flexible control devices which can be managed accordingly. Also use water level control in the riparian zone and upland areas to maintain wetland hydrology in providing planned functions.

Water level control can introduce the complexities of maintaining sediment balances, temperature elevation, change in channel substrate, changes in flow regime, and a host of other considerations which must be factored into designs and decisions for using the practice.

Design Considerations:

Inventory the existing soils, water regime, vegetation, fish and wildlife and use and spatial organization of the area under consideration. Determine the functional needs to be enhanced, restored or created. Specify the water level requirements over time and season. Evaluate the impact of implementing water level control on other functions and species of the system.

Check hydrology for feasibility of maintaining water levels through water budgets, soils analyses, vegetation, downstream impacts, timing and speed of fluctuations, and other considerations. Consider the possible impact of sediment accumulation. Provide for passage by aquatic species wherever possible.

Determine the method of water level control. Assure that the stream channel is stable. If not, consider restoration of the stream to a more natural alignment to achieve desired gradients. If a flow structure is to be used, investigate the site for subsurface geologic materials, design configuration and hydraulic detailing.

Control methods which require minimal operation are desirable. If the water level control structure is to be operated mechanically (such as an inflatable dam), assure that essential utilities are accessible, and that operation will be assumed by a responsible organization.

Prepare detailed operation plans.

Develop a detailed monitoring plan to assure that operation of the water level control device(s) is carried out and that water levels are achieved according to the operation plans.

Enlist the services of professionals, particularly for instream designs and installations.

Minimize disturbance to the stream and adjoining areas. For instream activities, schedule the work between migrations and during periods when resulting disturbances will least interrupt aquatic biota. If appropriate, divert flow around the work. Use appropriate erosion and sediment control practices. See Figure 54, page 103 for an illustration of a water control structure.

CHANNEL RECONSTRUCTION.

IMPOUNDMENT OF CUTOFF BENDWAYS.

(Information extracted from "Streambank Corridor Restoration Handbook.")

Impoundment of cutoff bendways involves the creation of a lake or pond by filling the upstream and downstream ends of old channel segments (often referred to as oxbows) at locations where they join the currently functioning stream. Oxbow ponds or lakes form naturally along abandoned courses of channel following alignment adjustments. These natural features can be duplicated along channels where alignment has been restored to provide valuable open water or wetland areas along the stream corridor. These can add to the ecological, recreational, and aesthetic functions and values of the corridor. Use this technique where channel alignment is being restored or adjusted and oxbows become available for conversion.

Impoundments can block existing drainage outlets. Permanent inundation can adversely impact affected biota. This technique is not appropriate if water supply of acceptable quality is not available. Oxbows may require the removal of heavy trash loads received during floods. May have a short life if subject to heavy sedimentation.

Design Considerations:

Investigate the impoundment water quality and the flushing rates that can be expected to avoid severe water quality deterioration. Inventory the oxbow drainage area. Plan for watershed treatment of significant non-point runoff sources. Perform a water budget analysis to assure that adequate inflow will be available. Supplemental inflow can be provided from the main stream. Plan for an outlet spillway as may be necessary.

Perform a geotechnical investigation to determine the sealing treatment which may be necessary within the storage area. Typically sealing will be required in old channel areas.

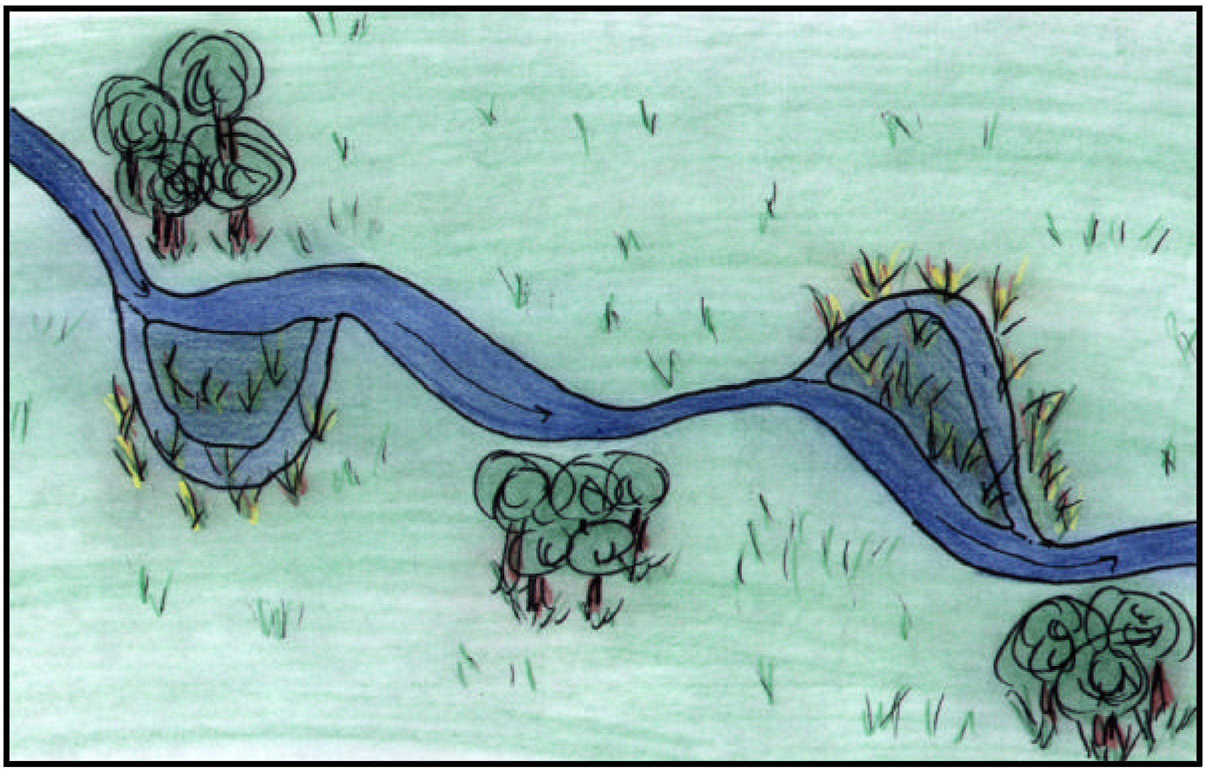
Perform an analysis of potential sedimentation to be sure that the pond will function for an acceptable period.

Determine the functions and values of the impoundment in terms of the stream corridor ecosystem and adjoining uplands and incorporate physical and vegetative features which will enhance habitat for targeted species.

Integrate soil bioengineering methods with toe protection to protect the embankment installations at the contacts with the live stream. Vegetate overbank flow channels in the vicinity of the impoundment to reduce erosion threats during flood flows.

Schedule installation following implementation of needed best management practices in the contributing drainage area.

Implement erosion sediment control measures prior to and during site disturbance activities. See Figure 64 for an illustration of this type of practice.



Impoundment of Cutoff Bendways **Figure 64**
adapted from "Streambank Corridor Restoration Handbook"

MAINTENANCE OF HYDRAULIC CONNECTIONS.

(Information extracted from "Streambank Corridor Restoration Handbook.")

When a channel is realigned, isolated channel bendways and other types of channel water bodies may lose their hydraulic connectivity and suffer reductions in ecological functions. With maintenance of hydraulic connections, flows are maintained through channel bendways. Use of this practice will assure that flows are maintained through the channel bendway and prevent losses of aquatic habitat area and diversity. Slackwater areas adjoining the main channel have potential for spawning and rearing areas for many fish species and are a key component of habitat for wildlife species that live in or migrate throughout the riparian corridor. Recreation value can be enhanced if connecting channels are deep enough for small boats or canoes.

Use this technique along reaches of realigned channel where cutoffs have been made and flow through channel bendways cutoffs needs to be maintained for the protection of riparian functions.

Not all streams will provide sufficient flows to maintain satisfactory hydraulic connections to the bendway. Sedimentation can require extensive maintenance.

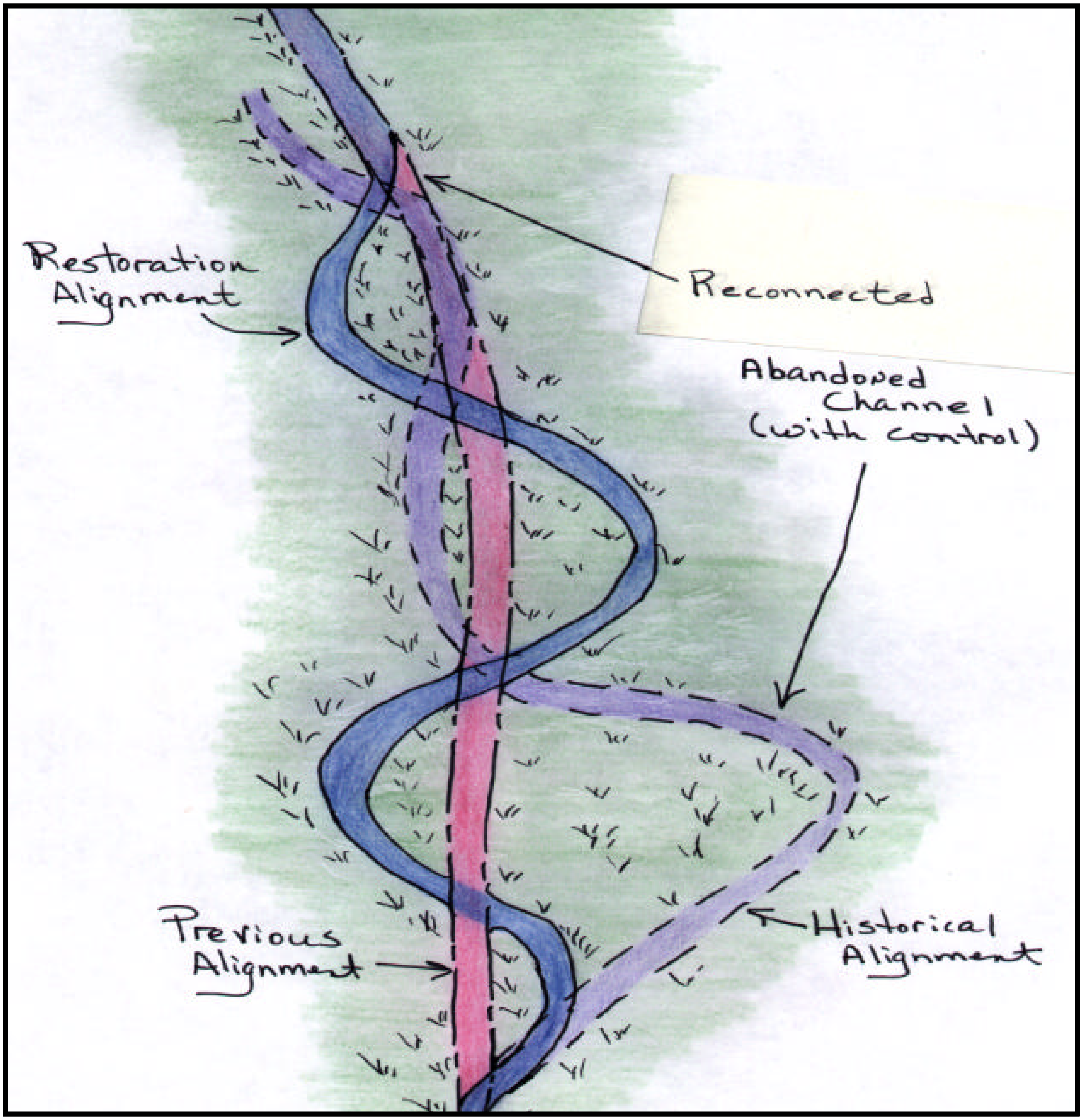
Design Considerations:

Obtain topographic surveys of the bypass and the bendway channels. Determine the flow requirements for the bendway to assure restoration of its aquatic and riparian functions.

Evaluate two or more techniques to provide for the flow diversion from the cutoff to the bendway. First the bypass channel may be constructed and stabilized with a channel bed higher than that of the bendway. Second, a sill or other type of flow control structure can be established in the bypass channel to assure that flow is diverted through the bendway.

Of these two techniques, the sill may be preferable because in the case of a raised cutoff channel there is a chance that flood flows would overtop the bypass channel and erode across the floodplain to the bendway.

Consider local drainage to the bendway and the cutoff channels. They could be impaired by changes brought about from hydraulic connections. Also consider water rights when planning for flow alterations.



Maintenance of Hydraulic Connections **Figure 65**
adapted from “Streambank Corridor Restoration Handbook”

STREAM MEANDER RESTORATION.

(Information extracted from "Streambank Corridor Restoration Handbook.")

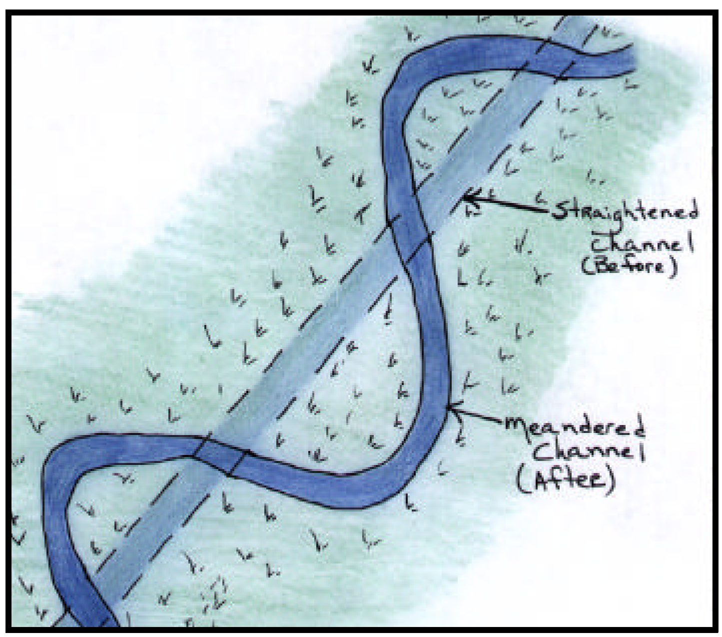
Stream meander restoration is the transformation of a straightened stream in a manner which emphasizes a channel size and meander relationships in conjunction with expected flow and sediment regimes and the geomorphology of the area. Many channels have been modified by straightening to provide additional flow capacity. This often resulted in channel instability in the constructed and adjacent areas. Channel meander restoration for the purposes of the referenced handbook means the restoration of the natural alignment, channel capacity and meander relationships to assure a functional, stable stream. Meandering channels offer physical stability and support natural ecological functions of the stream corridor. Meandering channels typically have higher levels of physical habitat diversity than straightened channels.

Channel meander restoration can be used to restore a straightened stream that was formerly meandering,

Meander reinstatement requires adequate space. Adjacent land uses may constrain locations. Therefore meander reinstatement may not be feasible in streams in watersheds experiencing rapid changes in land uses. These streams may require special considerations and forecasting. Channel meander restoration should not be carried out without consultation with, and inclusion of recommendations from, appropriate professionals including stream geomorphologists, hydrologists and stream corridor ecologists.

Successful channel meander restoration requires a comprehensive inventory of the deteriorated channel condition and its contributing watershed.

A logical first step is to identify stable channel planforms in adjacent watersheds that have similar watershed characteristics.



Stream Meander Restoration **Figure 66**

adapted from " Streambank Corridor Restoration Handbook"

STREAM CORRIDOR MEASURES.

LIVESTOCK EXCLUSION OR MANAGEMENT.

(Information extracted from "Streambank Corridor Restoration Handbook.")

Livestock exclusion is the protection of an area by preventing the entry of livestock. Fencing and provision of alternate sources of water and shelter are generally the key components of this practice. Use livestock exclusion to protect, maintain or improve the quantity of riparian plant and animal resources; to maintain cover and surface litter needed for soil and associated organisms; to maintain moisture; to maintain nutrient cycling and retention; to maintain cover and shading at the edge of stream; and to protect water quality.

Use wherever there is evidence that livestock grazing is negatively impacting the stream corridor by reducing growth of woody vegetation species, decreasing water quality or contributing to the instability of stream banks. Use exclusion techniques to keep livestock from directly entering the stream and the adjoining forested and other riparian buffers. Once the system has recovered, rotational grazing may be incorporated into the management plan.

Design Considerations:

This technique must be coordinated with an overall grazing plan for the livestock operation.

Livestock are frequently allowed to roam throughout riparian areas primarily to provide access to water, shading and grazing lands beyond; and secondly, to supplement grazing on nearby pastures or rangeland. Take into consideration that fencing keeps livestock out of riparian areas, but water, shade and access to grazing lands beyond must be provided. Initial expense for fence installation and yearly maintenance thereafter, are also considerations.

Identify the sensitive reaches of stream corridors which particularly need protection from livestock. Work with land users to evaluate their livestock management system, their short and long term grazing needs and goals, and alternatives for livestock exclusion along the sensitive reaches. Develop a livestock exclusion plan which includes at least the following considerations.

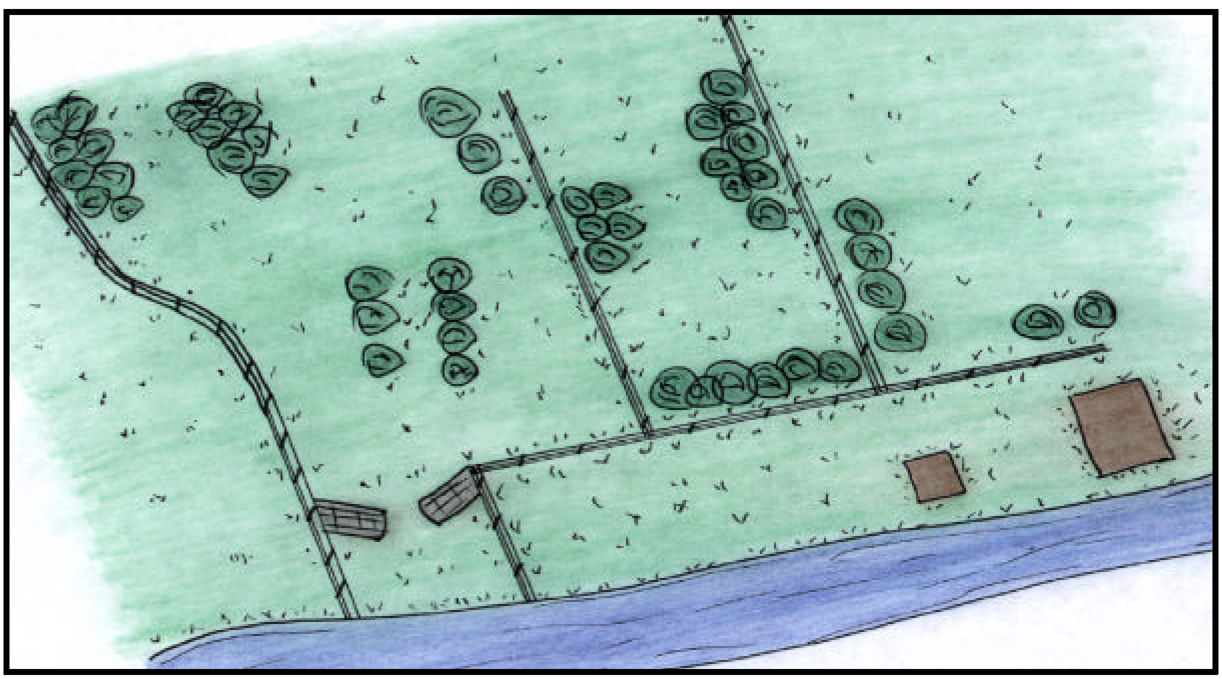
Identify locations where a water supply can be developed as alternative to stream access. Plan for shading requirements by utilizing or planting trees outside the riparian zone or installation of shade shelters or walls.

Identify locations that may be needed for access to grazing lands beyond the riparian zone. Plan a removable or temporary fenced lane through the riparian buffer and stream crossing at a riffle area, where the impact will be minimal. Include stream crossing protection where possible. The crossing can range from a rock lining in the bottom and up each slope to culverts or even timber bridges. Keep the crossing at least two (2) animals wide, but narrow enough that the livestock will not linger in the vicinity.

Fences need not be elaborate as long as they are effective. An electric fence, if properly maintained, works well and requires considerably less initial expense but requires monitoring. Electric fencing is particularly advantageous in regions of heavy ice flows, because it can be quickly removed and reinstalled.

More permanent fencing involves barbed wire, barbless wire, woven wire or wooden boards and metal or wooden posts. These may be more costly than electric, but involve less monitoring and maintenance.

There are numerous technical references for the installation of fencing, livestock crossings, spring developments, pumps, and watering troughs or tanks.



Livestock Exclusion or Management **Figure 67**

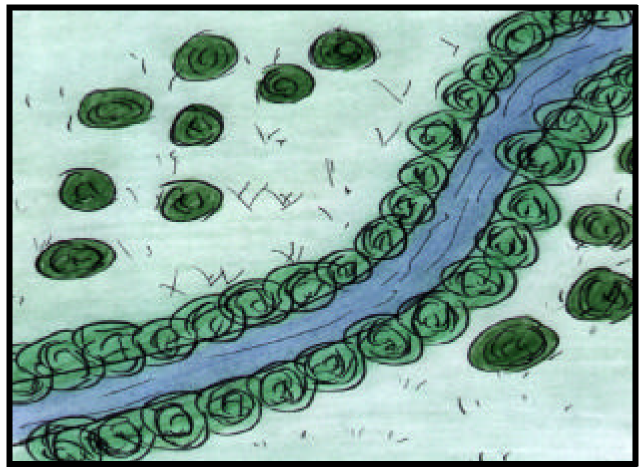
adapted from "Streambank Corridor Restoration Handbook"

RIPARIAN FOREST BUFFER.

(Information extracted from "Stream Corridor Restoration Handbook.")

A riparian forest buffer is an area of trees and/or shrubs located adjacent to and up-gradient from water bodies and water courses.

Riparian forest buffers are used to : 1) create shade and lower water temperatures to improve habitat for fish and other aquatic organisms; 2) provide a source of detritus and large woody debris for fish and other aquatic organisms and riparian habitat and corridors for wildlife; and 3) reduce excess amounts of sediment, organic material, nutrients, and pesticides and other pollutants in surface runoff and reduce excess nutrients and other chemicals in shallow ground water flow. Some other important benefits include corridors for wildlife, a stabilizing effect on eroding streambanks, additional products (timber, firewood, fiber, nuts, etc.) for the farm enterprise, and improvement of aesthetics and recreational opportunities at the site and landscape level.



Riparian Forest Buffer **Figure 68**
adapted from "Streambank Corridor Restoration Handbook"

This practice is applicable on stable areas adjacent to permanent or intermittent streams, lakes, ponds, wetlands and areas with ground water recharge. Unstable areas such as those with high surface erosion rates, mass soil movement or active gullies will need stabilizing treatment either before or concurrent with installation of a Riparian Forest Buffer.

Certain areas with toxic soil conditions such as saline seeps may not be suited to the establishment and growth of most woody species. Under these conditions, highly specialized plant material and supplemental water may be needed for the first several growing seasons. Also, sites in arid and semi-arid regions may not have sufficient soil moisture throughout the growing season to support woody plants. Concentrated flow erosion, excessive sheet and rill erosion or mass soil movement must be controlled in the up-gradient area prior to establishment of the riparian forest buffer.

The location, layout, width, length and woody plant density of a Riparian Forest Buffer are designed to accomplish the specific purpose and function.

Dominant vegetation consists of existing or planted trees and shrubs suited to the site and the intended purpose. Locally native species are required. Plantings ordinarily consist of two or more species with individual plants suited to the seasonal variation of soil moisture status of individual planting site. For multi-species and multi-story buffers, plant types and species are selected based on their comparability in growth rates and shade tolerance.

To create shade or provide detritus, the buffer consists of zone 1 that begins at the normal water line, or at the upper edge of the active channel or shoreline. It usually extends at least 15 feet wide.

To reduce excess amounts of sediment, nutrients and other pollutants, an additional strip or area of land (zone 2) will begin at the edge and up-gradient of zone 1. It usually extends at least 20 feet and, for water courses with wide active floodplains, may extend to 100 feet or more. A minimum of 50 feet is required to provide adequate supply of large woody debris. The mature height of the dominant species should be the minimum width of the zone providing large woody debris, usually around 75-150 feet (confirm this number with local species).

One-hundred to 200 feet is a suggested minimum to provide habitat for wildlife. Many Riparian Forest Buffers are designed for intentional harvesting of tree and shrub products (such as timber, nuts and fruit) and/or livestock grazing. For such buffers, a high level of harvesting or grazing control is crucial to maintain proper function.

The buffer site is prepared and planted at a time when soil moisture is sufficient (not frozen) and root growth potential of selected woody species is high.

Only viable, high quality, and adapted planting stock of sufficient size and root caliper is used. Planting stock may be hand or machine planted depending on site characteristics such as slope gradient. Proper depths and placements or roots is a crucial aspect of installation. For some species and sites, irrigation may be necessary to assure early survival and buffer functions.

DISCHARGE MANIPULATION.

FLOW REGIME ENHANCEMENT.

(Information extracted from "Stream Corridor Restoration Handbook.")

Flow regime enhancement involves changing the management of watershed features (such as land use or impoundment) to achieve an adjustment of streamflow behavior for added value to the stream's physical, chemical and ecological quality. Use flow regime enhancement to protect natural channel functions (e.g. sediment transport) and to improve aquatic habitat and water quality.

Human-induced changes in many watersheds have altered streamflow characteristics to the extent that the stream no longer supports one or more of its former functions. Flow regime enhancement can restore or improve threatened functions (e.g. substrate materials or distribution of flow velocities to support that natural food web).

Hydrologic modification may require extensive changes over broad areas involving many land users which may become expensive.

Traditionally, streamflow augmentation has been used for such objectives as remediation of depleted dissolved oxygen levels, reduction in salinity levels or to simply maintain a minimum flow level for downstream users. These are basic attempts to meet minimum requirements for water quality (e.g. dilution) or to satisfy downstream demand. An evaluation of the system is needed to determine what impacts from historical changes in the flow regime over time can be mitigated using flow enhancement techniques.

Document current stream and corridor conditions and the functions which need to be improved. Select those needs which appear to be related to streamflow, such as declines in baseflow, increases in the frequency of, and declines in the duration of, bankfull or higher discharges, significant changes in channel cross sections and bed levels, and significant changes in stream biota abundance and diversity.

Gather long term flow records and compare to the changes in land use and other flow-inducing conditions which may have occurred over the period. Track the changes which may have occurred in factors such as channel geometry, bed materials, velocity distribution, frequency of flooding and low flows, water quality, fish and invertebrates.

Characterize the factors which appear to be related to streamflow changes and describe the desired condition for them (e.g., low flows are now below levels that will support habitat and food webs for target species).

Determine what flow characteristics should be changed to achieve the desired improvements (annual maxima and minima, storm runoff durations, seasonal and annual volumes, 10 year - 7 day low flows, etc.).

Evaluate the watershed to determine measures that could achieve the desired flow enhancement. Calibrate hydrologic models for use in the calculations and perform water budget calculations. If there are water withdrawals or impoundment involved, determine if withdrawals and discharges can be scheduled or changed to better meet flow needs.

Treatment practices aimed at improving hydrologic conditions often require several years of effort because of the number of land users involved and the period required to establish planned measures.

FLOW TEMPERATURE MANAGEMENT.

(Information extracted from "Stream Corridor Restoration Handbook.")

Flow temperature management involves using strategies to reduce elevated streamflow temperature. Elevated temperatures in streams can change the composition and diversity of aquatic organisms, increase the vulnerability to toxic materials, parasites and diseases, reduce oxygen supply, and even use by cold water species. Slugs of cold or warm water releases from reservoirs can have drastic impacts on downstream biota during critical reproduction periods. Techniques may be effective in governing stream temperature problems.

Flow temperature management may be effective along small streams, in watersheds with little vegetative cover or unnaturally high sediment loads, and below reservoirs.

It is increasingly difficult to impact stream temperature with watershed size.

Smaller streams where bank vegetation can provide substantial shading of the channel and on which much of the canopy has been removed are best candidates for controlling stream temperature. See Figure 68. Other opportunities may be afforded by increasing the infiltration capacity of watershed land, hence increasing the cooling during subsurface flow, manipulation of flow releases from reservoirs, controlling excessive erosion of drainage areas, and, as applicable, reducing the quantity of irrigation return flows.

Restoration of bank canopy can provide stream shading along narrower channels and provide temperature relief. This approach will be less effective on larger rivers.

In smaller watersheds, an increase in the infiltration capacity of the contributing landscape will provide for cooler-subsurface flow to the stream. Improvements in the hydrologic conditions of various land uses will all contribute.

Turbid water absorbs more solar radiation than clear. Therefore erosion control in watersheds can also help in reducing thermal pollution.

Flow releases from cooler strata of reservoirs must be exercised with care. Although cooler, water from this source is generally low in dissolved oxygen and must be aerated before discharging downstream. Selective mixing of the reservoir withdrawal can moderate temperatures as may be required.

In irrigated areas, there may be opportunities to cool return flows prior to discharge to streams.

FLUSHING FOR HABITAT RESTORATION.

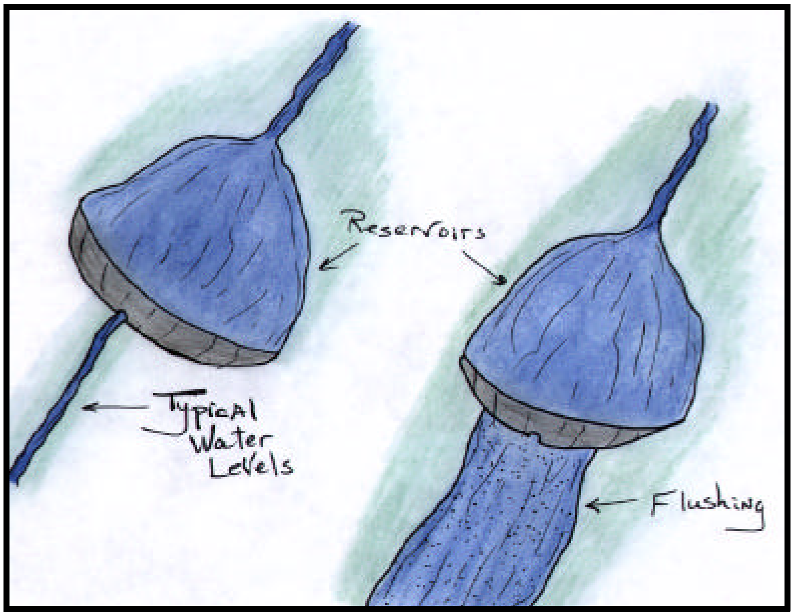
(Information extracted from "Stream Corridor Restoration Handbook.")

Flushing for habitat restoration is a practice below reservoirs in which a high-magnitude, short duration release is made to scour the accumulation of fine-grained sediments from the streambed.

This practice is used to restore suitable instream habitat, including gradation of streambed materials, suppression of aquatic vegetation, maintenance of stream channel geometry necessary to provide instream habitat, and floodplain scouring to provide suitable growing conditions for riparian vegetation. Deposits of gravel and cobble free of finer sediments are essential for some aquatic species. Prolonged low flows downstream of dams sometimes degrade these habitats by allowing fine sediments to deposit on and within coarse sediments.

Use this technique for habitat restoration as part of an overall instream management program in areas downstream of water development projects.

Flushing flows of a large magnitude may cause flooding of old floodplains below dams or cause depletion of gravel substrates and drastic alterations to channel geometry. Flushing of fine sediments at one location may simply translate the problem to other downstream areas.



Flushing for Habitat Restoration **Figure 69**

adapted from "Streambank Corridor Restoration Handbook"

Evaluate the system below the impoundment(s) to determine the optimum flushing regimen for restoration of habitat for key species and any downstream impacts which may result. Use tools such as sediment transport and habitat models.

Determine what modifications to the impoundment works are feasible for meeting the flushing flow rate, volume and duration requirements. Alternatives such as sluicing, turbine pulsing, or regulation weirs may be available.

Seasonal discharge limits, rate of change of flow, and river stages downstream of impoundment may need to be considered to avoid damage to instream and riparian habitat.

The coordination of operation and monitoring functions will be key following installation of the flow modification devices. Monitoring of the streambed materials, channel geometry, aquatic vegetation and other features downstream needs to be conducted frequently and coordinated with the release operations of the impoundment to assure that the intended objectives are met and to avoid adverse effects.

WATERSHED MANAGEMENT PRACTICES/BEST MANAGEMENT PRACTICES.

AGRICULTURE.

(Information extracted from "Stream Corridor Restoration Handbook.")

Best management practices (BMP's) for agriculture are solitary and systematic approaches aimed at mitigating non-point source pollution. Agricultural management systems can incorporate a number of innovative and proven alternatives that improve environmental quality.

Agricultural land can include:

- Cattle and crop production enterprises;
- Orchards;
- Nurseries;
- Market gardens;
- Pastures;
- Grazing lands;
- Farmlands that are not actively producing crops, such as wetlands, farm woodlots, and field borders.

The application of BMP's will mitigate the potential negative effects of some farming operation methods. Many restoration techniques applied to a stream corridor could be ineffective if non-point source pollution is not controlled.

These practices should be used where current management systems are causing problems on-site or within farm or field boundaries. They may also be applied where watershed management plans are being implemented to improve environmental quality. Below, in Table 3, a partial listing of the more widely used BMP's are provided and the expected impacts on the downstream ecosystem are identified.

When applying a BMP, consider how it fits within a comprehensive farm management plan, a watershed action plan, or a stream corridor restoration project. Doing so can improve future land use options, rotations through farm growing seasons, and the benefit of having the best management system in place.

Crop management should consider the four seasons conservation of the soil, water and microbial resources base. Tillage, seeding, fertilizing, pest management, and harvest operations should consider environmental qualities and the potential to use adjacent lands in water and soil conservation and management, and pest management.

TABLE 3 - SELECTED IMPACTS OF AGRICULTURAL BEST MANAGEMENT PRACTICES							
BEST MANAGEMENT PRACTICE	PRACTICE IMPACTS (From the "Stream Corridor Restoration Handbook")						
	REDUCES SEDIMENT	REDUCES WIND EROSION	REDUCES SURFACE RUNOFF	REDUCES NUTRIENTS/ PESTICIDES	IMPROVES VISUAL LANDSCAPE	IMPROVE WATER QUALITY	IMPROVE WILDLIFE HABITAT
Conservation Cover	D	D	D	D	D	D	I
Contour Farming	D	D	D	I	I	D	I
Critical Area Planting	D		D	I	D	D	D
Field Border	D	I	D	D	I	D	D
Filter Strip	D	I	D	D	I	D	I
Forest Land Erosion Control	I	I	D	I	D	D	D
Forest Land Management	D	D	D	D	D	D	D
Hedgerow Planting	D	I	D	D	D	D	D
Herbaceous Wind Barriers	I	D	I	I	D	I	D
Livestock Exclusion	D	D	I	D	D	D	I
Nutrient Management	I		I	D	I	D	I
Pasture & Hayland Management	D		D	D	I	D	I
Pest Management		I		D		D	I
Proper Grazing Use	D		D	D	I	D	I
Proper Woodland Grazing	D	I	D	D	I	D	I
Recreation Area Improvement	D	I	D	I	D	D	I

TABLE 3 cont. - SELECTED IMPACTS OF AGRICULTURAL BEST MANAGEMENT PRACTICES							
BEST MANAGEMENT PRACTICE	PRACTICE IMPACTS (From the "Stream Corridor Restoration Handbook")						
	REDUCES SEDIMENT	REDUCES WIND EROSION	REDUCES SURFACE RUNOFF	REDUCES NUTRIENTS/ PESTICIDES	IMPROVES VISUAL LANDSCAPE	IMPROVE WATER QUALITY	IMPROVE WILDLIFE HABITAT
Recreation Trail & Walkway	D	I	D	I	D	D	I
Residue Management	D	I	D	D	I	D	D
Riparian Forest Buffer	D	D	D	D	D	D	D
Sediment Basin	D	D	D	D		D	D
Strip Cropping	D		D	D	D	D	D
Tree/Shrub Establishment	D	D	I		D	I	D
Water & Sediment Control Basin	D	I	D	D		D	I
Water Spreading	D		D	D		D	I
Wetland Development or Restoration	D		D	D	D	D	D
Wildlife Upland Habitat Management	I		I	I	D	I	D
Wildlife Watering Facility	I		I	I	D	D	D
Windbreak/Shelterbelt Establishment	I	D	I	I	D	I	D
Windbreak/Shelterbelt Renovation	I	D	I	I	D	I	D

KEY: D (Direct Impact), I (Incidental Impact) and Blank (Impact depends on circumstances)

Grazing land management should protect environmental attributes, including native species protection, while achieving optimum, long-term resource use.

Where crops are raised and the land class allows, pastures should be managed with crop rotation sequences to provide vigorous forage cover while building soil and protecting water and wildlife qualities.

Orchards and nursery production should actively monitor pest and water management techniques to protect ecosystem quality and diversity.

Farm woodlots, wetlands, and field borders should be part of an overall farm plan that conserves, protects, and enhances native plants and animals, soil, water, and scenic qualities.

FOREST LAND.

(Information extracted from "Stream Corridor Restoration Handbook.")

Forest land, in this description, includes all land areas on which trees are the predominant vegetative cover wherever they may occur in the landscape.

When applying a Best Management Practice (BMP), consider how it fits within a comprehensive Forest land management plan, a watershed action plan, or a stream corridor restoration project. Table 4 shows a listing of forest land management practices and the expected impacts on the downstream ecosystem are identified. Guidelines for some specific categories of forest land management are as follows:

- Forest land management, as it may impact the stream corridor, includes preharvest planning, streamside management measures, road construction or reconstruction, road management, timber harvesting, site preparation and forest generation, fire management, revegetation of disturbed areas, forest chemical management, and forest wetland management.

- Preharvest planning is particularly important to ensure that silviculture activities, including timber harvests, site preparation, and associated road construction, are conducted in a manner that minimizes non-point source runoff to streams, protects the integrity of the stream corridor, and considers the impacts to wildlife habitat.

- Assure that the functions of the stream corridor are not threatened by streamside management measures which are intended to provide a buffer between the harvesting operations and the stream.

- Preplan skid trails, landing locations, and haul roads on stable soils, avoid steep grades, landslide prone areas, high erosion hazard areas, and poorly drained areas. Systematically design transportation systems to minimize total mileage and keep stream crossings to a minimum.

- Avoid harvesting during excessively wet periods. Yard or land logs uphill. Keep logging debris away from the stream channels. Manage landings to prevent erosion and excessive runoff. Skid uphill or along the contour. Retire skid trails by installing erosion control measures and revegetating.

- Site preparation for regeneration should avoid placing slash (cuts) in drainageways, and should not be carried out on saturated soils. Operate planting machines on the contour to avoid ditch formation.

- Burning should be conducted during periods of favorable weather, time of year, and fuel conditions that will help achieve the desired results and minimize the impacts on water quality and wildlife. Restrict burning in the streamside management area. All necessary permits must be obtained and the appropriate local authorizing agencies that oversee burns contacted.

- Revegetation of disturbed areas should focus on high priority areas first, including exposed areas in streamside management areas and on steep slopes. Use mixes of species and treatments developed or tailored for the region or area.

- Chemicals should only be applied by skilled and licensed applicators according to the registered use, with special consideration given to impacts to nearby surface waters.

- Careful consideration must be given to the protection of forested wetlands including avoidance of any activities which will adversely impact the hydrology or quality of water and other materials which may enter them.

TABLE 4 - SELECTED IMPACTS OF FOREST LAND MANAGEMENT							
BEST MANAGEMENT PRACTICE	PRACTICE IMPACTS (From the "Stream Corridor Restoration Handbook")						
	REDUCES SEDIMENT	REDUCES SURFACE RUNOFF	REDUCES NUTRIENTS/ PESTICIDES	PROTECTS VISUAL LANDSCAPE	PROTECTS WATER QUALITY	PROTECTS WILDLIFE HABITAT	PROTECTS STREAM BIOTA
Access Road Entrance	D		I	I	I		I
Berms	D		I		D	I	I
Broad Based or Rolling Dips	D		D		D		I
Brush Barrier	D		D		D	I	I
Drainage Structures	D		D		D		I
Filter Strips	D		D		D		D
Fire Management	D	D	D	I	D	I	I
Fish Passageways							D
Forest Chemical Management			D		D	D	D
Forest Road Maintenance	D		D	I	D		I
Forest Road Planning, Design, Installing	D	D	D	I	D	D	D
Grading, Mulching, and Seeding	D	I	D		D	I	I
Habitat Protection Areas				I		D	D

TABLE 4 - SELECTED IMPACTS OFD FOREST LAND MANAGEMENT							
BEST MANAGEMENT PRACTICE	**PRACTICE IMPACTS (From the "Stream Corridor Restoration Handbook")**						
	REDUCES SEDIMENT	**REDUCES SURFACE RUNOFF**	**REDUCES NUTRIENTS/ PESTICIDES**	**PROTECTS VISUAL LANDSCAPE**	**PROTECTS WATER QUALITY**	**PROTECTS WILDLIFE HABITAT**	**PROTECTS STREAM BIOTA**
Harvesting Mngmnt.	D	D	D		D	D	D
Integrated Pest Management			D		D		D
Petroleum Mngmnt.			D		D	D	D
Post Harvest Mngmnt.	D	D	D	D	D	D	D
Pre-Harvest Planning	D	D	D	D	D	D	D
Revegetation of Disturbed Areas	D	D	D	D	D	D	D
Sediment Detention Basin	D		D		D		D
Shade Strips		I		D	D	I	D
Silt Fence	D		D		D		D
Skid Trails	D	D	D	D	D	D	D
Stream Crossing Structures	D		D		D		I
Streamside Management Zone	D	D	D	D	D	D	D
Water Bars and Water Turnouts	D		D		D		D
Wetland Protection	I		D	D	I	D	D

KEY: D (Direct Impact), I (Incidental Impact), and blank (Impact depends on circumstances)

URBAN AREAS.
(Information extracted from “Stream Corridor Restoration Handbook.”)

Urban areas, described here, are land areas which have been converted from forest land, agriculture, range or idle land uses to those principally used for residential, industrial, commercial, transportation, and utility functions.

Urban areas can have severe impact on the natural environment of a stream corridor. BMP’s are needed in urban areas to restore, protect and enhance watershed functions, which in turn mitigate the potential negative effects of urban activities on the stream corridor.

BMP’s should be used throughout the various urban complexes where current management is impairing or causing the deterioration of the natural watershed functions. The most efficient practices are those which are included in the original development plans. Retrofitting of older developments is far more expensive and challenging.

The use of individual urban BMP’s should be coordinated with an overall plan for restoring the stream system. Urban sites are highly variable and have a high potential for disturbance.

Urban BMP’s should be part of the comprehensive plan for management of the system or watershed even if the watershed covers more than one jurisdiction. This will assure that related dysfunctions are appropriately addressed.

GEORGE PALMITER RIVER RESTORATION TECHNIQUES.
(Information adapted from IWR Contributing Report 82-CR1)

Mr. Palmiter developed his techniques through experimentation over many years while attempting to make rivers near his home navigable for canoes and small boats. The rivers had become choked with fallen trees and log jams after severe wind storms. By cutting log jams, floating logs and other materials into eroded banks and observing the results, Palmiter constructed and refined his methods.

The Palmiter techniques require a minimum of equipment, relying more upon human labor. His focus is to "Let the River Do the Work." The river provides most of the needed raw materials in log jams and nearby trees and shrubs. Human labor, hand tools and occasionally, a tractor or mule are used to cut and move the jams. Logs and other debris are then placed at strategic points in the river channel. The strategically placed materials direct the existing currents away from eroded banks or into sand and gravel bars which need to be removed because they are blocking the channel. The new flow pattern resembles what would happen without human intervention and is therefore relatively permanent. Furthermore, the techniques employ an overall river management approach rather than simply controlling erosion, and symptoms are treated and the problems eliminated.

There are six (6) steps to the Palmiter techniques: 1) remove log jams; 2) protect eroded banks; 3) remove sand and gravel bars; 4) revegetation; 5) remove potential obstructions; and 6) maintenance.

Remove Log Jams. Fallen trees and log jams alter the flow characteristics and slow the current to a point where sediments are deposited because the current can no longer move the sand and gravel. Jams may also divert the current into one of the banks, causing erosion. By removing fallen trees and jams, the unimpeded current can erode away nearby sand and gravel bars and bank erosion is minimized. Much or all of the material cut from the log jams is used to protect eroding banks.

Protect Eroded Banks. Erosion is caused typically by rapid currents which undercut the riverbank. This occurs where the current is diverted around an obstruction like a log jam or a sand and gravel bar, or against the outside bank of a river bend. If the erosion is caused by an obstruction, then the obstruction must be removed.

Palmiter's approach to protecting eroded banks involves placing and securing a tree top or other brushy material on the river bank upstream from the erosion site. This brush pile changes the current flow, creating two (2) beneficial effects. First, the main current is diverted out into the main channel away from the eroded bank. Secondly, the current is decreased in the brush pile and immediately downstream, allowing sediments to be deposited in these places.

Generally, the diverted current flow will again touch the bank downstream. A second brush pile is anchored there, and so on throughout an entire problem area. Several well-placed brush piles will divert the current toward the center of the channel and may actually begin erosion of any sand and gravel bar on the opposite bank of the river. Furthermore, sediments will continue to build in the brush piles.

Remove Sand and Gravel Bars. Sand and gravel bars occur for a variety of reasons wherever the current velocity is decreased. They form most frequently, however, just downstream from log jams and fallen trees. They can also occur as point bars on the inside bank of river bends opposite eroded banks. If the jam or fallen tree is removed, the bar will usually be eroded away by the uninhibited current flow. Likewise, point bars are often eroded away by the current flow created when brush piles are used to protect eroded banks. But if these two (2) techniques fail to remove the point bar, further work will be needed.

This work would involve the placement of current deflectors and the digging of pilot channels. A type of current deflector used here are large brush piles of tree tops which are anchored far into the river channel. They divert the current into the point bar, thereby undercutting it. Small but deep pilot channels, or trenches, are also dug, usually by hand, through the bar. Water entering the pilot channel will erode the point bar. Eventually, a substantial portion of the current will pass through the pilot channel.

Revegetation. Reestablishing the vegetation needs to be taken in two (2) places: 1) in the newly-deposited sediments in the brush piles and 2) along the bank where there is no vegetation. The planted vegetation will grow roots to stabilize and secure sediment and banks. This encourages further sedimentation in the brush piles. Also, the vegetation will grow leafy branches which provide shade for the river. The shade is very important in preventing the growth of aquatic plants in the main channel. Additionally, the shade helps keep the water cool, an important factor in maintaining fish and aquatic wildlife populations.

Removing potential obstructions. Potential obstructions are those trees which are in imminent danger of falling into a waterway. These are either standing dead trees or trees which are severely leaning over the channel. The trees can have the tops or branches which lean over the channel removed. In the last resort, these trees must be completely cut down. Standing dead and mature harvestable trees may be cut and used for lumber or firewood. These trees are cut, leaving the root structures and a short stump intact. The root structures are important in stabilizing banks and protecting them from erosion and new growth may occur from the old stump.

The goal of removing potential obstructions is to prevent these trees from falling into the river and becoming an obstruction in the future, while at the same time leaving a good, strong stand of trees and shrubs along the bank for bank stabilization and shade. Trees that aren't in danger of falling into the river need not be removed and may have valuable wildlife benefits.

Maintenance. After a stretch of river has been restored, periodic reexaminations are necessary. This is to assure that past work was adequate to alleviate channel problems. The reexamination is also necessary to determine if any new work is needed. Reexaminations are particularly important after periods of high water when the erosive force of the waterway is greatest.

STREAM OBSTRUCTION REMOVAL GUIDELINES (SORG).

(Information obtained from The Wildlife Society and American Fisheries Society.)

The intent of SORG is to aid in correcting stream flow problems, caused by obstructions, in an environmentally sound manner and to maintain natural stream characteristics. These are a positive alternative, designed to protect natural resources, to be used when a government agency or other interests are considering channelization, clearing and snagging, or other severe stream modifications. The purpose is not to generate projects, but to provide a sound alternative that will lessen adverse impacts when a decision has been made to correct stream flow problems.

For further information, contact The Wildlife Society and American Fisheries Society.

CHAPTER IV. - CONCLUSIONS AND RECOMMENDATIONS.

Conclusions. Seventy-nine engineering features and other techniques were discussed and many of them illustrated in this handbook. Areas that were covered included: Bank Treatment, Instream Practices, Structures for Ponds, Lakes and Wetlands, and Coastal Areas. Also included were management measures that covered broader areas in comparison to the ones prior mentioned. These included: Backwater Management, Channel Reconstruction, Stream Corridor Measures, Discharge Manipulation, and Watershed Management Practices. Two (2) other methods, which entailed debris and log removal and how to use this to help restore the river or stream were also briefly discussed.

The main objective of this handbook is to identify and describe examples of various environmental engineering features or management measures or techniques and their components. This handbook is intended to stimulate planners and others involved in this area by identifying and illustrating types of techniques that are available. The aim for this handbook is not a design manual, but rather to provide sufficient information to inspire plan formulation and assist the planners in identifying what is out there and to be able to "visualize" how an environmental type engineering feature(s) can fit into their project.

Again, this is in no way inclusive of all the engineering features or techniques that are available or are being developed. This handbook should be considered a living document, meaning, more engineering features can be added in the future. The majority of the techniques presented in this handbook, were found to be the more frequently used techniques. This is not to say that techniques not presented in this handbook were unpopular or unsuccessful.

There is considerable information available on the subject matter of environmental restoration design, and more is being developed. The Reference Section of this handbook, Appendix B, and the WEB sites, Appendix C, are good sources for perusal. State and Federal Agencies are also useful sources of information. Again, updated handbooks will include more references and WEB sites.

If there is current literature and/or WEB sites that should be included in future handbooks, please write to Ms. Joy Muncy, Institute for Water Resources, 7701 Telegraph Road, Casey Building, Alexandria, Virginia, 22315-3868. OR e-mail: joy.d.muncy@usace.army.mil

Recommendations. The first recommendation is to support additional work to make this handbook more comprehensive. Again, as mentioned before, there are many more techniques that need to be assembled for planners and others involved to know what is available to help them meet their study and project objectives.

Another recommendation, is to consolidate this handbook and future ones along with other reports developed from this work unit from EEIRP which are: the *National Review of non-Corps Environmental Restoration Projects*, IWR Report 95-R-12, the *National Review of Corps Environmental Restoration Projects*, IWR Report 96-R-27, the *Prototype Information Tree for Environmental Restoration Plan Formulation and Cost Estimation*, IWR Report 95-R-3, and *Planning Aquatic Ecosystem Restoration Monitoring Programs*, IWR Report 96-R-23. Implementation of the use of products from EEIRP and other research programs may enhance future documentation. As experience with these products expands, there may be more consistency between objectives, output measures, and improved cost documentation.

If the *Prototype Information Tree for Environmental Restoration Projects,* IWR Report 96-R-27, is further developed, it would be very useful to be able to link the designs from this handbook to the Information Tree.

Another recommendation is to provide the above, not only in a written format, but in some type of automated software. This software could be widely distributed to project/study managers. The database could be readily expanded and upgraded as implementation and research continues.

If software is developed, one other recommendation would be to interconnect this software with other software developed within EEIRP, such as IWR-PLAN. Once the engineering features and/or alternatives and their costs are determined, they could be automatically imported to the IWR-PLAN program to conduct cost effectiveness and incremental cost analysis.

APPENDIX A - GLOSSARY

Abiotic: Not biological; not involving or produced by organisms. Non-living, as opposed to living, or "biotic;" examples of biotic factors controlling biological activity include pH, temperature, moisture, and chemicals.

Abrasion: Removal of streambank soil as a result of sediment-laden water, ice, or debris rubbing against the bank.

Accretion: Natural accretion is the buildup of land, solely by the action of the forces of nature, on a beach by deposition of water-borne or airborne material. Artificial accretion is a similar buildup of land by reason of an act of man, such as the accretion formed by a groin, breakwater, or beach fill deposited by mechanical means.

Aerobic: Requiring oxygen or in the presence of oxygen.

Aggradation: The long-term hydraulic process by which streambeds and floodplains are raised in elevation by the deposition of materials. It is the opposite of degradation.

Aggregation (Soil): Where many soil particles are held in a single mass or cluster such as a clod, crumb, block, or prism.

Algae: Simple, usually microscopic, rootless plants that usually grow in water, that have no true root, stem or leaf.

Algal Blooms: A large population of algae that is obvious to the naked eye; usually caused by an abundance of nutrients in the water.

Alongshore: Parallel to and near the shoreline.

Alluvial: Deposited by running water.

Anadromous: Fish or other organisms that are born in freshwater, and migrate to and live in salt water, and then return to freshwater to reproduce.

Anaerobic: Life or processes that occur in the absence of oxygen; a condition where oxygen is absent.

Aquatic: Growing or living in or upon water.

Armoring: The natural process of forming an erosion resistant layer of relatively large particles on the surface of the streambed.

Artificial Headlands: Man-made offshore structures connected to the shoreline to provide coastal protection or to restrict longshore transport.

Available Water Capacity: The capacity of soil to hold water for use by plants.

A-Zone: Flood zone subject to still-water flooding during storms that have a 100-year recurrence interval.

Backbarrier Flats: Low-lying sand regions on the landward side of sand dunes. Often covered with salt-tolerant grasses and shrubs.

Backbarrier Marsh: Marsh formed behind a coastal barrier, often containing significant coarse sediment that has washed in from the seaward side.

Backrush: The seaward return of water following the uprush of the waves. For any given tide stage, the point of farthest return seaward of the backrush is known as the limit of backrush.

Backshore: Zone of the shore or beach including the berm or berms which lies between the foreshore and the dunes or bluffs. The backshore is acted upon by waves only during severe storms, especially when combined with exceptionally high water.

Backfill: The process of filling a cavity with soil, gravel rock or other material of choice.

Backwater Area: The low-lying lands adjacent to a stream that become flooded during periods of high water.

Baling Wire: Wire used for the purpose of tying down live brush mattresses and tying together live brush fascines. Typically, 10 to 20 gage non-galvanized steel wire is used.

Bank: The part of the soil next to a stream, lake or body of water where the soil elevation adjacent to the water is higher than the water level.

Bank Failure (Slip): Collapse of a mass of bank material into a stream channel.

Bankfull Discharge: The discharge corresponding to the stage at which the natural channel is full. This flow, on average, has a recurrence of 1.5 years. It is expressed as the momentary maximum or instantaneous peak flow rather than the mean daily discharge.

Bankfull Mean Depth: The mean depth of flow at the bankfull stage, determined as the cross-sectional area divided by the bankfull surface width.

Bankfull Width: The surface width of the stream measured at the bankfull stage.

Bar: A submerged or emerged mound of sand, gravel or shell material built on the ocean floor in shallow water by waves and currents.

Barrier Island: A type of coastal barrier completely detached from the mainland. Barrier spits may become barrier islands if their connection to the mainland is severed by creation of a permanent inlet. The barrier island represents a broad barrier beach, commonly sufficiently above high tide to have dunes, vegetated zones, and wetland areas.

Barrier Lagoon: A bay roughly parallel to the coast and separated from the open ocean by barrier islands or spits.

Barrier Spit: A type of coastal barrier which extend into open water and are attached to the mainland at only one (1) end. They can develop into a bay barrier if they grow completely across a bay or other aquatic habitat. On the other hand, bay barriers can become spits if an inlet is created.

Baseflow: Normal stream flow resulting from ground water drainage.

Bathymetry: The measurement of depths of water; also information derived from such measurements.

Bay: A recess in the shore or an inlet of a sea between two (2) capes or headlands, not as large as a gulf but larger than a cove.

Bay Barrier: A type of coastal barrier that connects two (2) headlands, and enclose a pond, marsh, or other aquatic habitat. The term by mount bar or bay bar are considered to be synonymous.

Beach: A zone of unconsolidated material that extends landward from the low water line to the place where there is marked change in material or physiographic form, or to the line of permanent vegetation (usually the effective limit of storm waves.)

Beach Barriers: See Dune.

Beach Berm: That area of shoreline lying between the swash zone and the dune system.

Beach Erosion: The carrying away of beach materials by wave action, tidal currents, littoral currents or wind.

Beach Face: The section of the beach normally exposed to the action of wave uprush. The foreshore of a beach.

Beach Nourishment: The supply of sediment by mechanical means to supplement sand on an existing beach or to build up an eroded beach.

Bed: The bottom of a channel, creek, river, stream, or other body of water.

Bed Load: Sediment moving along or near the streambed and frequently in contact with the streambed.

Bed Slope: The gradient from the horizontal plane of the channel bottom.

Bench: A horizontal surface or step in a slope.

Belt Width: The width of the full lateral extent of the bankfull channel measured perpendicular to the fall of the valley.

Bend: A change in the direction of a stream channel in plan view.

Berm: In a barrier beach system, the relatively flat, sandy area between the berm crest and the dunes formed by the deposit of material by wave action. Some beaches have no berm, others have one (1) or several.

Berm Crest: The seaward limit of a berm.

Bioengineering: The application of vegetative practices combined with structural practices to provide a system of practices that create a stable site condition.

Biotic: Caused or produced by living beings.

Blanket: Material placed on a streambank or lakeshore to cover eroding soil.

Block and Gravel Inlet Protection (Sediment Traps and Barriers): A temporary sediment control barrier formed around a storm drain inlet by the use of standard concrete block and gravel, to filter sediment from storm water entering the inlet prior to stabilization of the contributing area soils, while allowing use of the inlet for storm water conveyance.

Blowout: The removal of sand from a dune by wind drift after protective dune vegetation has been lost. Unless repaired promptly, the area of blowout will increase in size and could lead to the development of a migrating sand dune and its associated problems.

Bluff: A high, steep bank or cliff.

Bog: Wetland in northern Europe and North America with a high water table and little significant flow of water in or out of the area; consisting of peat deposit and supporting the growth of acid-loving plants, especially, *Sphagnum*.

Bottomland: Periodically flooded lowland adjacent to rivers and streams, often forested Coastal plain. Region of sandy, peaty soil supporting sparse growth longleaf pine; historically, subject to periodic fires; from Virginia south through the Carolinas; natural habitat of many specialized plants, such as Venus-flytrap (*Dionaea muscipula*), pitcher plants (*Sarracenia* spp.), and numerous orchids.

Boulder: Sediment particle having a diameter greater than 10 inches.

Braided Stream: A stream that forms an interlacing network of branching and recombing channels separated by branch islands or channel bars.

Branchpacking: Consists of alternative layers of live branch cuttings and compacted backfill to repair small localized slumps and holes in slopes.

Breakwater: A linear, floating or mound-like coastal engineering structure constructed offshore parallel to the shoreline to protect a shoreline, harbor or anchorage from storm waves.

Brushlayer: Live branch cuttings laid in crisscross fashion on benches between successive lifts of soil.

Brushlayering: Cuttings or branches are layered between successive lifts of soil fill to construct a reinforced slope.

Brush Barriers: Piles of slash material piled at the toe slope of a road or at the outlets of culverts, turnouts, dips and water bars. Also should be installed at the foot of fills if the fills are located inside 150 feet of a defined stream channel.

Brush Mattress: A live construction that places living branches close together to form a mattress-like cover over the ground. This mattress is intended to grow and protect the bank from erosion.

Buffer Zone: An appropriately managed and unalienated zone of unconsolidated land between beach and development, within which coastline fluctuations and hazards can be accommodated in order to minimize damage to the development.

Buttressing and Arching (In regards to woody vegetation): Anchored and embedded stems can act as buttress piles or arch abutments t counteract downslope shear forces.

Bypassing Sand: Hydraulic or mechanical movement of sand, from an area of accretion to a downdrift area of erosion, across a barrier to natural sand transport such as an inlet or harbor entrance. The hydraulic movement may include natural movement as well as movement caused by man.

Cable and Clamp: Galvanized steel cable in a PVC plastic jacket to hold construction materials to anchor.

Caving: The collapse of a streambank by undercutting due to wearing away of the toe or an erodible soil layer above the toe.

Catchment: An area confined by drainage divides usually having only one (1) streamflow outlet.

Caving: The collapse of a streambank by undercutting due to wearing away of the toe or an erodible soil layer above the toe.

Channel: A natural or artificial waterway that periodically or continuously contains moving water. It has a definite bed and banks that confine the water.

Channelization: Straightening of a stream or the dredging of a new channel to which the stream is diverted.

Channel Roughness: The irregularity of streambed material sizes and channel form in plan and cross-section that causes resistance to flow.

Channel Scour and Fill: Erosion and sedimentation that occurs during relatively short periods of time; degradation and aggradation apply to similar processes that occur over a longer period of time.

Channel Stability: A relatively measure of the resistance of a stream or river to erosion. Stable reaches do not change markedly in appearance from year to year.

Check Dam: A small dam constructed across an influent, intermittent drainageway to reduce channel erosion by restricting flow velocity. They are not meant for live streams. They serve as emergency or temporary measures is small eroding channels that will be filled or permanently stabilized at a later date, such as in a construction setting.

Clay: Cohesive soil whose individual particles are not visible to the unaided human eye. Soil can be molded into a ball that will not crumble.

Coast: The strip of land, of indefinite width (up to several miles), that extends from the shoreline inland to the first major change in terrain features.

Coastal Barriers: Unique land forms that provide protection for diverse habitats and serve as the mainland's first line of defense against the impacts of severe coastal storms and erosion. Located at the interface of land and sea, the dominant physical factors responsible for shaping coastal land forms are tidal range, wave energy, and sediment supply from rivers and older, pre-existing coastal sand bodies.

Coastal Structures: Those structures on the coastline designed to protect and rebuild the coastline and/or enhance amenity and use.

Coastline Hazards: Detrimental impacts of coastal processes on the use, capability and amenity of the coastline.

Cobble: Sediment particles larger than pebbles and smaller than boulders. Usually three (3) to eight (8) inches in diameter.

Coir: Tough fibers produced from the husk of coconuts.

Coir Fascine: Biodegradable coir fiber cylindrical bundles with a diameter of 12, 16, or 20 inches, usually manufactured as 20 foot long modules.

Coir Mats: Coir mats are dense, biodegradable mats are usually made of coconut fiber (coir), used to protect streambanks and wetland shores from erosion, trap sediment and provide a stable substrate for wetland plants.

Coir Webbing: An open weave biodegradable erosion control fabric with a non-shifting square mesh consisting of 100 percent coir fiber yarns in both the warp and the weft.

Concentrated Flow: Runoff water from sheet or uniform flow that converges at a common area. Concentrated flow can cause gullies on unprotected soil surfaces.

Concentrated Flow Erosion: Erosion resulting when concentrated water flows across land and removes the soil during runoff. The eroded area is usually shallow enough to be crossed with farm equipment, but can develop into a gully.

Confinement: The lateral containment of rivers as quantitatively determined by meander width ratio (meander width ratio is determined by dividing belt width by bankfull.)

Constructed Wetland: Engineered systems designed to simulate natural wetlands to exploit the water purification functional value for human use and benefits. Constructed wetlands consist of former upland environments that have been modified to create poorly drained soils and wetlands flora and fauna for the primary purpose of contaminant or pollutant removal from wastewaters or runoff. Constructed wetlands are essentially wastewater treatment systems and are designed and operated as such even though many systems do support other functional values.

Contour Farming: The practice of farming in which the row patterns follow the contours of the landscape.

Converted Wetland: A wetland that was drained, dredged, filled, leveled, or otherwise manipulated, including the removal of woody vegetation, or any activity that results in impairing or reducing the flow, circulating or reach of water, and makes the production of an agricultural commodity possible.

Cover: Anything that provides protection for fish and/or wildlife from predators or alleviates adverse conditions of streamflow and/or streamflow and/or seasonal changes in metabolic costs. May be in-stream structures such as rocks or logs, turbulence, and/or overhead vegetation.

Crib Structure: A hollow structure constructed of mutually perpendicular, interlocking beams.

Crimpers: Dull-bladed coulter disks.

Cross Section: A vertical section of a stream channel or structure that provides a side view of the structure; a transect taken at right angles to the flow direction.

Current: The flow of water moving in a particular direction.

Current, Littoral: Any current in the littoral zone cause primarily by wave action, i.e., longshore current, rip current.

Current, Longshore: The littoral current in the breaker zone that moves essentially parallel to the shore, usually generated by waves breaking at an angle to the shoreline.

Cusp: Scallop-like ridges and depressions in the sand spaced at regular intervals along the beach.

Cutbank: The steep or overhanging slope on the outside of a meander curve, typically produced by lateral erosion of the stream.

Cutting: A branch or stem pruned from a living plant.

Cut Face: The open, steep face of an excavated slope.

D30, D50, D85: The particle size for which 30, 50, and 85 percent of the sample is finer.

Damage Potential: The susceptibility of coastline development to damage by coastline hazards.

Deadman: A log or block of concrete, or other material buried in a streambank that is used to tie in a revetment with cable, chain, or steel rods.

Dead Stakes: Stakes, varying in length, made from lumber, used to hold construction materials in place.

Debris: Any material, organic, or inorganic, floating or submerged, moved by a flowing stream or water body.

Deflectors: Hardened structures anchored in the streambank and protruding into the current with an upstream face that is angled downstream at approximately 45 degrees from the flow.

Degradation: The long-term hydraulic process by which a stream and river beds lower in elevation. It is the opposite of aggradation.

Deposition: The settlement of material out of the water column and onto the streambed or floodplain. Occurs when the flowing water is unable to transport the sediment load.

Design Wave Height: The wave height adopted for the purposes of designing coastal structures such as breakwaters and seawalls. It is chosen to ensure that the structures are not at undue risk of wave damage.

Detention Basin: A basin such as a small pond or reservoir that temporarily stores runoff water and releases the water downstream in such a manner that reduced the peak flow.

Dike: A structure designed to reduce the water velocity as streamflow passes through the dike so that sediment deposition occurs instead of erosion (permeable dike) or to deflect erosive currents away from the streambank (impermeable dike.)

Discharge: Volume of water flowing in a given stream at a given place and within a given period of time, usually expressed as cubic meters or cubic feet per second (cfs.)

Distressed Streambank: A bank that has (or is) suffering from erosion or failure.

Dormant Season: The non-growing season for woody species, when they have grown their buds, and photosynthesis in the leaves has stopped.

Downdrift: In the direction of the predominant movement of sediment along the shore. The side of a groin, jetty or other structure which is deprived of sand.

Drainage Basin: A land surface collecting precipitation into one (1) stream, sometimes referred to as a watershed.

Dredging: The removal of sediment or the excavation of tidal or subtidal bottom to provide sufficient depths for navigation or anchorage, or to obtain material for construction or for beach nourishment.

Dune (Beach Barriers): Any natural hill, mound or ridge of sediment landward of a coastal berm deposited by the wind or by storm overwash. Sediment deposited by artificial means and serving the purpose of storm-damage prevention and flood control.

Dune Field: The system of developing dunes, foredunes and hinddunes that is formed on sandy beaches to the rear of the beach berm.

Dune Maintenance: The management technique by which dunes, dune vegetation and dune protective structures are kept in good "working order;" activities may include weed/pest/fire control, replanting, fertilizing, repair of fences and access ways, and publicity.

Dune Management: The general term describing all activities associated with the restoration and/or maintenance of the role and values of beach dune systems; dune management activities and techniques include planning, dune reconstruction, revegetation, dune protection, dune maintenance, and community involvement.

Dune Protection: The management technique by which the dune system is protected from damage by recreational and development activities; dune protection activities generally include the use of fences, access ways and signposts to restrict and control access to dune systems.

Ebb Tide: The period of tide between high water and low water. A falling tide.

Ecosystem: An ecological system; the interacting system of a biological community and its non-living environment; a basic functional unit of nature comprising both organisms and their nonliving environment, intimately linked by a variety of biological, chemical, and physical processes.

Ecotone: Transitional zone between two (2) adjacent plant communities, such as a meadow and a forest.

Eddy Current: A circular water movement that develops when the main flow becomes separated from the bank.

Emergent Plants: Sedges, rushes, cattails, and other such herbaceous plants that are rooted in substrate and protrude above the water's surface.

Embankment (Bank): The part of the soil next to the stream, lake r body of water where the soil elevation adjacent to the water is higher than the water level.

Enhancement: Improvements to the existing conditions of the aquatic, terrestrial, and recreational resources.

Entrance Instability: Refers to the tendency of entrances to estuaries and coastal lakes to migrate along the shore, close up, reopen, form new entrances, etc. in response to wave and current action and freshwater flows.

Entrenchment Ratio: The quantitative index of the vertical containment of rivers as determined by dividing the flood-prone area width by the bankfull width. (The flood-prone area width is measured at twice the maximum bankfull depth.)

Erosion: The wearing away of land by the action of natural forces. On a beach, the carrying away of beach material by wave action, tidal currents, littoral currents, or wind.

Estuary: The part of a river that is affected by tides. The region near a river mouth in which the freshwater of the river mixes with the saltwater of the sea.

Excavated Drop Inlet Protection (Sediment Traps and Barriers): A temporary excavated area around a storm drain drop inlet or curb inlet designed to trap sediment prior to discharge into the inlet.

Eutrophication: The natural or artificial process of nutrient enrichment often resulting in a water body becoming filled with algae and other aquatic plants.

Eutrophic Lake: A lake that has high level of nutrients, especially phosphorus and nitrogen, and a high level of biological productivity; oxygen content may be extremely high during sunny days and very low at night and on overcast days due to a high level of photosynthetic action.

Fabric Drop Inlet Protection (Sediment Traps and Barriers): A temporary fabric barrier placed around a drop inlet to help prevent sediment from entering storm drains during construction operations, while allowing use of the inlet for storm water conveyance.

Face Planting: Planting live cuttings and other vegetation in the frontal openings of retaining structures.

Fascine (Wattles): A securely bound, thick roll consisting of live or dead branches, coir, or other organic or inorganic material.

Fetch: The distance over the water in which waves are generated by a wind having a rather constant direction and speed.

Filter: Layer of fabric, sand, gravel, or graded rock placed between the bank revetment or channel lining and soil for one (1) or more of three (3) purposes: to prevent the soil from moving the revetment; to prevent the revetment from sinking into the soil; to permit natural seepage from the streambank, thus preventing buildup of excessive groundwater pressure. Also called filter layer or filter blanket.

Fish Habitat: The aquatic and surrounding terrestrial environment that meet the necessary biological and physical requirements of fish species during various life stages.

Flanking: Streamflow between a structure and the bank, possibly occurring because the structure was not properly tied into the bank.

Floodplain: Level land adjacent to a river periodically covered by, floodwaters.

Flood Frequency Analysis: Uses a probability of a given magnitude flood peak that may be expected to occur for a given return period expressed in years. For example, the "1 in 100 year" flood would have a probability of 0.01 or one (1) percent of being equaled or exceeded in one (1) year.

Flood-prone Area Width: The width associated with a value of twice the bankfull depth. It is the area including the floodplain of the river and often the low terrace of alluvial streams. The value when divided by the bankfull width is used to determine the entrenchment ratio.

Flood Tide: The period of tide between low water and high water. A rising tide.

Forbland: For coastal areas; area characterized by low, herbaceous or slightly woody plants, annual or sometimes perennial (not grasses.)

Foredune: The larger and more mature dune lying between the incipient dune and hinddune area. Foredune vegetation is characterized by grasses and shrubs. Foredunes provide an essential reserve of sand to meet erosion demand during storm conditions. During storm events, the foredune can be eroded back to produce a pronounced dune scarp.

Fluvial: Produced by moving water.

Ford: A shallow stream crossing; the streambed is often surfaced with stone or other material.

Foredune: The front dune immediately behind the backshore.

Foreshore: The steeper part of the beach that extends from the low water mark to the upper limit of high tide. The beach face.

Fringing Mangroves: Bands of mangrove along subtropical or tropical mainland shores in areas of low wave energy. Many of these areas are located behind coral reefs, which together with the mangroves themselves, provide significant protection for the mainland from storm impact.

Gabion: A wire mesh basket filled with rock that can be used in multiples as a structural unit.

Geogrid: A fabric with high-tensile strength and width, frequent, apertures consisting of long-lasting plastic materials.

Geotextile Fabric: A manmade fabric used in the control of soil erosion. The fabric is available in roles of various widths and lengths and usually vary from one manufacturer to the other. Also known as Filter Fabric.

Grade Stabilization: The maintenance of a gentle, non-eroding gradient on a watercourse of land surface.

Grade Stabilization Structure: A structure designed to reduce channel grade in natural or constructed watercourses to prevent erosion of a channel that results from excessive grade in the channel bed or artificially increased channel flows.

Grass-Lined Channel (Runoff Conveyance Measure): A swale vegetated with grass, which is dry except following storms and serves to convey specified concentrated storm water runoff volumes, without resulting in erosion, to disposal locations.

Gravel: Sediment particles larger than sand and ranging from two (2) to 64 mm in diameter.

Gravity Retaining Walls: Retaining structures that resist lateral earth forces and overturning primarily by their weight.

Greenbelt: Strip of trees and shrubs growing parallel to a stream that prevents overuse of the top of bank area by man, animals, and machinery. This strip of vegetation also retards rainfall runoff down the bank slope and provides a root system which binds soil particles together.

Groin: A narrow, elongated coastal-engineering structure built on the beach perpendicular to the trend of the beach. Its purpose is to trap longshore drift to build up a section of beach.

Groundwater: That portion of the soil or rock where all pore spaces are completely saturated; the water that occurs in the earth below the depth to which water will rise in a well.

Gully: A channel or void in the landscape associated with erosion and concentrated form of water. A gully is distinguished from a rill by its depth - a gully is too deep to be crossed by farm equipment while a rill can be crossed and may be smoothed by ordinary tillage methods (i.e., breaking or discing.) Active gullies are usually significant producers of sediment.

Habitat: The environment in which an organism naturally lives or grows; the environment in which the life needs of a plant, animal, population or community are supplied.

Hardened Channel (Runoff Conveyance Measure): A channel with erosion-resistant linings of riprap, paving, or other structural material designed for the conveyance and safe disposal of excess water with erosion.

Headcutting: The action of an upstream moving waterfall or locally steep channel bottom with rapidly flowing water through an otherwise placid stream. These conditions often indicate that a readjustment of a stream's discharge and sediment load characteristics is taking place.

Headland: An area of high elevation more resistant to erosion than surrounding areas and less susceptible to flooding. Headlands can supply sand and gravel to beaches.

Herbaceous: Plant species, either annual , or perennial with soft, flexible stems, and no woody parts.

High Tide: The maximum elevation reached by each rising tide.

Hinddunes: Sand dunes located to the rear of the foredune. Characterized by mature vegetation including trees and shrubs.

Hurricane: An intense tropical cyclone with winds that move counterclockwise around a low-pressure system. Maximum sustained winds of 74 miles per hour or greater.

Hydraulics: The science of laws governing the motion of water and other liquids and their practical applications in engineering.

Hydraulic Radius: The cross-sectional area of a stream or river divided by the wetted perimeter.

Hydrology: The scientific study of water found on the earth's surface, its subsurface, and in the atmosphere; the science dealing with the properties, distribution and circulation of water and snow.

Hydrophytic: Water tolerant or water loving.

Impermeable: Properties that prevent the movement of water through the material.

Incipient Dune: The most seaward and immature dune of the dune system. Vegetation characterized by grasses. On an accreting coastline, the incipient dune will develop into a foredune.

Incised Channel: A stream that through degradation has cut its channel into the bed of the valley.

Infiltration: The downward entry of water into the soil.

Infiltration (Vegetation): Plants and their residues help to maintain soil porosity and permeability, thereby delaying onset of runoff.

In-stream Cover: Areas of shelter in a stream channel that provide aquatic organisms protection from predators or competitors or solar heating. A place in which to rest and conserve energy due to a localized reduction in the force of the current.

Interception (Vegetation): Foliage and plant residues absorb rainfall energy and prevent soil detachment by raindrop splash.

Intermittent Stream: A watercourse that flows only at certain times of the year, receiving water from springs or surface sources; also, a watercourse that does not flow continuously, when water losses from evaporation or seepage exceed available stream flow.

Jetty: A narrow, elongated coastal-engineering structure built perpendicular to the shoreline at inlets. Designed to prevent longshore drift from filling the inlet and to provide protection for navigation.

Joint Planting: The process of placing live woody plant cuttings in the spaces between pieces of riprap. When placed properly, the cuttings are capable of rooting and growing.

Lacustrine: Of, or relating to, growing in a lake.

Lake: An open-water wetland deeper than eight (8) feet and larger than 20 acres situated in a topographic depression or dammed river channel (as an oxbow or impoundment) without trees, shrubs, or emergent plants.

Lagoon: A shallow body of water, as a pond or lake, usually with a limited connection to the sea.

Large Woody Debris: Any large piece of woody material that intrudes or is embedded in the stream channel or lakeshore.

Lateral Earth Pressure: Horizontal pressure exerted by soil against a retaining structure.

Level Spreader (Outlet Protection): An outlet designed to convert concentrated runoff to sheet flow and disperse it uniformly across a slope without causing erosion.

Life of Project: An estimated time period over which a structure will function if limited only by deterioration of materials.

Littoral: The benthic zone between high tides; living in or taking place in the shallow waters of lakes or the sea.

Littoral Drift: The sedimentary material moved in the littoral zone under the influence of waves and currents.

Littoral Shelf: A bench in the shallow water zone with a gentle ground slope formed by processes of wave erosion.

Littoral Transport: The movement of littoral drift in the littoral zone by waves and currents. Includes movement parallel (longshore transport) and perpendicular (on/offshore transport) to the shore.

Littoral Zone: In beach terminology, an indefinite zone extending seaward from the shoreline to just beyond the breaker zone.

Live Cribwall: A hollow, structural wall formed out of mutually perpendicular and interlocking members, usually timber, in which live cuttings are inserted through the front face of the wall into the crib fill and or natural soil behind the wall.

Live Branch Cuttings: Living, freshly cut branches of woody shrub and tree species that propagate from cuttings embedded in the soil.

Live Fascines: Bound, elongated sausage like bundles of live cut branches that are placed in shallow trenches, partly covered with soil, and staked in place to arrest erosion and shallow mass wasting.

Live Stake: Cuttings from living branches that are inserted and tamped into the earth. The stakes eventually root and leaf out.

Live Stake Planting: Live stake planting is the planting of live, rootable, vegetative cuttings into the ground.

Longshore Currents: Currents flowing parallel to the shore within the inshore and nearshore zones. Longshore currents are typically caused by waves approaching the beach at an angle. The "feeder" currents to rip cells are another example of longshore currents.

Low-Head Dam (Weir): Essentially the same type of construction as the check dam, built from rocks, logs, or other material, but intended for use in lower order perennial streams for water quality improvement and habitat enhancement.

Low Tide: The minimum elevation reached by each falling tide.

Lower Bank: That portion of the streambank below the elevation of the average water level of the stream.

Marsh: An area of soft, wet or periodically inundated land, generally treeless and usually characterized by grasses and other low growth.

Mass Movement: The movement of large, relatively intact masses of earth and or rock along a well defined shearing surface as a result of gravity and seepage.

Mannings "n": The resistance coefficient in the Manning formula used in calculating water velocity and stream discharge. It is a proportionality coefficient that varies inversely as a function of flow.

Meander Width Ratio: The quantitative expression of confinement (lateral containment of rivers) and is determined by the ratio of belt width/bankfull width.

Mean High Water: The average height of all of the high waters recorded at a given place over a 19-year period.

Mean Low Water: The average height of all of the low waters recorded at a given place over a 19-year period.

Mean Sea Level: The average height of the surface of the sea at a given place for all stages of the tide over a 19-year period.

Mulching (Conventional): Used for decades for immediate seed and soil protection from erosive forces and to accelerate vegetation establishment. Straw and hay are the most commonly used mulching materials. Benefits of mulches include:

- assisting in soil stabilization, which immediately reduces wind and water erosion.
- reducing soil temperatures, which decreases soil moisture evaporation and heat stress upon plants.
- capturing and retains moisture, which reduces soil moisture loss.
- capturing blowing snow, and increases the insulating effect of winter precipitation.
- decomposing into valuable organic matter that becomes incorporated into the soil.

Navigable Streams (Waterways): Waterways of sufficient depth and width to handle a specified traffic load.

Neap Tide: A tide occurring near the time of quadrature of the moon with the sun. The neap tide range is usually 10- to 30-percent less than the mean tidal range.

Noncohesive Soil: Soils that have little natural resistance to being pulled apart at their point of contact. Typically soils such as sand and gravel.

Nonpoint Source Pollution: Pollution arising from an ill-defined and diffuse source, such as runoff from cultivated fields, grazing land, or urban areas.

Northeaster: On the U.S. east coast, a storm (low-pressure system) whose counterclockwise winds approach the shore from the northeast as the storm passes an area. Its steeper waves approaching from the opposite direction to normal lower waves can cause coastal erosion.

Nourishment: The placement of sediment on a beach or dunes by mechanical means.

Obligate Wetland Plant: Plant always found growing in wetlands under natural conditions (may persist in nonwetlands that have been drained or if planted there.)

Offshore Bar: Also known as a longshore bar. Submerged sandbar formed offshore by the processes of beach erosion and accretion. Typically, swell waves break on the offshore bar.

Offshore Breakwater: Offshore structure built parallel to the beach to protect the beach and/or reduce wave action in inshore waters.

Onshore/Offshore Transport: The process whereby sediment is moved onshore and offshore by wave, current and wind action.

Ordinary High Water Mark: The mark along a streambank where the waters are common and usual. This mark is generally recognized by the difference in character of the vegetation above and below the mark or the absence of vegetation below the mark.

Outlet Stabilization Structure (Outlet Protection): A structure designed to control erosion at the outlet of a channel or conduit by reducing flow velocity and dissipating flow energy.

Overbank Flow: Water flowing over the top of the bank.

Overhead Cover: Material (organic or inorganic) that provides protection to fish or other aquatic life from above.

Overwash: The uprush and overtopping of a coastal dune by storm waters. Sediment is usually carried with the overwashing water and deposited, usually in a fan shape, on the landward side of the dune or barrier.

Oxbow (Oxbow Lake): Portion of a former riverbed when the bend is cut off from the main stream in a U-shaped form

Palustrine: Refers to wetlands with water less than six (6) feet deep; area dominated by trees, shrubs and that are in, or relate to marshes.

Paved Flume (Runoff Conveyance Measure): A small concrete-lined channel to convey water down a relatively steep slope without causing erosion.

Peak Flow: The maximum rate of runoff that occurs from a watershed during a storm event.

Peat: Incompletely decayed dead plant material that has accumulated in low-oxygen conditions.

Perennial Stream: Watercourse that flows continuously throughout the year.

Permanent Seeding: Establishment of perennial vegetative cover with seed to minimize runoff, erosion, and sediment yield on disturbed areas. Disturbed soils typically require amendment with lime, fertilizer, and roughening. Mixtures are typically most effective, and species vary with preferences, site conditions, climate, and season.

Permit: A document granting permission to do something.

Pile: A long, heavy timber, pipe, or section of concrete or metal to be driven or jetted into the earth to serve as a support for a bulkhead, pier, etc.

Pile Rot: The rotting of wood pile caused by being exposed to the weather.

Piping: Flow of water through subsurface conduits in the bank.

Pocket Beaches: Small beach systems typically bounded by rocky headlands. Because of the presence of the headlands and the small size of these beaches, longshore currents are relatively insignificant in the overall sediment budget.

Point Bar: A bar found on the inside bank of a river at a bend.

Point Source Pollution: Pollution coming from a well-defined origin, such as the discharge from a pipe at an industrial plant.

Pond: A small body of water, usually artificially created by damming, diking or excavating. Smaller and shallower than a lake. Usually one (1) to eight feet deep and generally less than eight (8) acres.

Pothole: Shallow, marsh-like pond that may dry up at times of low rainfall; found in the prairie states, especially Minnesota, North Dakota, and South Dakota, and adjacent regions of Canada.

Rapid Drawdown: Lowering the elevation of water against a bank faster than the bank can drain leaving a pressure imbalance that may cause the bank to fail.

Reach: A length of stream that has generally similar physical and biological traits.

Reinforced Concrete: Used to armor eroding sections of streambank by constructing retaining walls or bulkheads. Positive drainage behind these structures must be provided. Reinforced concrete may also be used as a channel lining.

Restoration: To return a degraded site or condition to its former healthy state or to a less degraded condition.

Restraint (Vegetation): Root systems physically bind or restrain soil particles while above ground portions filter sediment out of runoff.

Retardation (Vegetation): Stems and foliage increase surface roughness and slow velocity of runoff.

Revetment: A facing of stone, wood, or natural materials, placed on a bank as protection against wave action or currents. For coastal areas, an apron-like, sloped, coastal-engineering structure built on a dune face or fronting a seawall. Designed to dissipate the force of storm waves and prevent undermining of a seawall, dune of placed fill.

Rill Erosion: An erosion process in which numerous small channels only several inches deep are formed; occurs mainly on recently cultivated soils and/or recent cuts and fills.

Riparian Area: Vegetated ecosystems along a lotic or flowing waterbody through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding and influence from the adjacent waterbody. These systems encompass wetlands, uplands, or some combination of these two (2) land forms; they do not in all cases have all of the characteristics necessary for them to be classified as wetlands.

Riparian Vegetation: Vegetation growing along the banks of streams and rivers or other bodies of water tolerant to or more dependent on water than plants further upslope.

Rip Currents: Concentrated currents flowing back to sea perpendicular to the shoreline. Rip currents are caused by wave action piling up water on the beach. Feeder currents running parallel to the shore (longshore currents) deliver water to the rip current.

Riprap: A layer, facing, or protective mound of stones randomly placed to prevent erosion, scour or sloughing of a structure or embankment. Also the stone so used.

Riverine: Referring to a wetland habitat contained within a channel; situated beside a river; or, relating to, or growing in or on the banks of a river.

River Training Works: Structures placed in a stream to direct the current into a predetermined channel.

Rock: Soil particles greater than three (3) inches in diameter.

Rootwad/Rootball: The root mass of the tree, often used in the construction of a bank revetment.

Root Reinforcements (In regards to woody vegetation): Roots mechanically reinforce a soil by transfer of shear stress in the soil to tensile resistance in the roots.

Root Zone: The depth of soil penetrated by plant roots.

Runoff: The portion of precipitation or irrigation water that flows off a field, feedlot or other impermeable or saturated surface. The water that flows off the surface of the land without infiltration onto the soil is called surface runoff.

Runoff Diversion: Structure that channels upslope runoff away from erosion areas, diverts sediment-laden runoff to suitable traps or stable outlets, or captures runoff before leaving site, diverting it where it can be used or released without erosion or flood damage.

Salt Marsh: A marsh periodically flooded by salt water.

Sand: Mineral particles ranging from 0.0025 to 0.08 inch diameter; 0.03 inch is the normal lower limit at which the unaided human eye can distinguish an individual particle.

Sand Bypassing: A procedure whereby sand deposited on the updrift side of a training wall or similar structure is mechanically delivered to the downdrift side. This facilitates the natural longshore movement of the sediment.

Sand Drift: The movement of sand by wind. In context of coastlines, “sand drift” is generally used to describe sand movement resulting from natural or man-induced degradation of dune vegetation, resulting in either nuisance or major drift. Sand drift can damage buildings, roads, railways and adjoining natural features such as littoral rainforest or wetlands; sand drift can be a major coastline hazard.

Scarp: An almost vertical slope along the beach caused by erosion by wave action. It may vary in height from a few inches to several feet, depending on wave action and the nature and composition of the beach. (Also occurs on river and stream banks.)

Scour: Concentrated erosive action of flowing water in streams that removes material from the bed and banks.

Seawall: A vertical, wall-like coastal engineering structure built parallel to the beach or dune line and usually located at the back of the beach or the seaward edge of the dune.

Sediment (Sedimentation): Solid particles or masses of particles that originate from the weathering of rocks and are transported, suspended in, or deposited by air, water or ice, or by other natural agents such as chemical precipitation and organic secretion.

Sediment Basin/Rock Dam (Sediment Traps and Barriers): An earthen or rock embankment located to capture sediment from runoff and retain it on the construction site, for use where other on-site erosion control measures are not adequate to prevent off-site sedimentation.

Sediment Fence (Silt Fence)/Straw Bale Barrier (Sediment Traps and Barriers): A temporary sediment barrier consisting of filter fabric buried at the bottom, stretched, and supported by posts, or straw bales staked into the ground, designed to retain sediment from small disturbed areas by reducing the velocity of sheet flows.

Sediment Load: The sediment transported through a channel by streamflow.

Sediment Trap (Sediment Traps and Barriers): A small, temporary ponding basin formed by an embankment or excavation to capture sediment from runoff.

Seepage: Groundwater emerging on the face of a streambank.

Sheet Erosion: The removal of a fairly uniform layer of soil material from the land surface by the action of rainfall and surface runoff.

Sheet Flow: Runoff water that flows uniformly over the soil surface.

Sheet Pile: A pile with a slender flat cross section to be driven into the ground and meshed or interlocked with similar sheets to form something like a bulkhead. Made out of aluminum, fiberglass, steel, vinyl, wood or other suitable materials.

Silt: Slightly cohesive to noncohesive soil composed of particles that are fine than sand but coarser than clay, commonly in the range of 0.004 to 0.0625.

Siltation: The filling of a waterbody or wetland by waterborne sediment.

Sinkhole: Natural depression or opening on the land surface which often includes a channel or hole leading directly to ground water; usually in areas underlain by cavernous limestone.

Sinuosity: A measure of the amount of a river's meandering; the ratio of the river length to the valley length. A straight channel has a sinuosity of 1.0; a fully meandering river has sinuosity of two (2) or greater.

Slope Scaling: This remedial activity (usually done by hard labor) involves grading the slope to fill in rolls and gullies, slumps, and other depressions that concentrate surface runoff. Slope scaling is necessary to repair slopes prior to wattling, brush packing or erosion control blanket installation.

Slough: Shallow swamp or marsh with sluggish, slowly, flowing water.

Sloughing: The downward slipping of a mass of soil, moving as a unit usually with backward rotation, down a bank into the channel. Also called sloughing off or slumping.

Sod Drop Inlet Protection (Sediment Traps and Barriers): A permanent grass sod sediment filter area around a storm drain drop inlet for use once the contributing area soils are stabilized.

Sodding: Permanent stabilization of exposed areas by laying a continuous cover of grass sod. Sod is useful for providing immediate cover in steep critical areas and in areas unsuitable for seed, such as flowways and around inlets. Sod must be rolled over after placement to ensure contact, and then watered. Sodded waterways and steep slopes may require netting and pegging or stapling.

Soil: Soil finer than sand but coarser than clay, but not so fine that it can remain suspended in water for long periods.

Soil Moisture Depletion (In regards to woody vegetation): Evapotranspiration and interception in the foliage can limit buildup of positive pore water pressure.

Species Diversity: The measure of the variety of species in a community that takes into account the relative abundance of each species.

Spillway: A designed surface passageway for excess runoff water to pass.

Spring Tide: A tide that occurs at or near the time of new of full moon and that rises highest and falls lowest from the mean sea level.

Step/Pool Channel: The type of bed features associated with the slope and bankfull width of the stream. The bed features are generally chutes and scour pools whose pool-to-pool spacing is inversely related to the stream slope and is proportional to the bankfull width.

Straw Rolls: Long bags or nets filled with straw or similar material. They are placed along the contour of a slope or streambank in order to reduce erosion and sedimentation. Commonly uses wood or live stakes to anchor the roll in place.

Streambank: The portion of the channel cross-section that restricts lateral movement of water. A distinct break in slope form the channel bottom.

Streambank Erosion: Removal of soil particles from a bank slope primarily due to water action. Climatic condition, ice and debris, chemical reactions, and changes in land and stream use may also lead to bank erosion.

Streambank Failure: Collapse or slippage of a large mass of bank material into the channel.

Stream Stability: The ability of a stream to transport the water and sediment of its watershed in such a manner to maintain its dimension, pattern, and profile, over time, without either aggrading nor degrading.

Stream Slope: The change in elevation of the bed surface over a measured length of channel. It is expressed as a ratio of elevation (rise) over distance (run) in ft/ft..

Submerged Plant: Plant that is rooted in soil and grows below the water's surface.

Surcharge (In regards to woody vegetation): Weight of vegetation can, in certain instances, increase stability via increased confining (normal) stress on the failure surface.

Surf Zone: The area between the outermost breaker and the limit of wave uprush.

Surface Roughening: Roughening a bare, sloped soil surface with horizontal grooves or benches running across the slope. Grooves can be large-scale, such as stair-step grading with small benches or terraces, or small-scaled, such as grooving with disks, tillers, or other machinery, or with heavy tracked machinery which should be reserved for sandy, noncompressible soils. Roughening aids the establishment of vegetative cover, improves water infiltration, and decreases runoff velocity.

Surface Runoff: That portion of rainfall that moves over the ground toward a lower elevation and does not infiltrate the soil.

Suspended Load: The part of the total sediment load that is carried for a considerable period of time at the velocity of the flow, free from contact with the streambank.

Swash Zone: That area of the shoreline characterized by wave uprush and retreat.

Tackifiers: As bank slope angles increase, crimping techniques are replaced by viscous oversprays, which are used to anchor the mulch fibers to themselves and to the ground. These oversprays, called "tackifiers," generally are composed of asphaltic emulsions; petroleum distillates; emulsions of co-polymer acrylates, latexes and polyvinyl acetates; and dry powdered vegetable gums derived from guar, psyllium and sodium alginase. Tackifier application rates vary depending on the type of product, severity of site conditions, climate and desired longevity of the installation.

Temporary Seeding: Planting rapid-growth annual grasses, small grains, or legumes to provide initial, temporary stabilization for erosion control on disturbed soils that will not be brought to final grade for more than approximately one (1) month. Seeding is facilitated by fertilizing and surface roughening. Broadcast seeds must be covered by raking or chain dragging, while hydroseed mixtures are spread in a mulch matrix.

Temporary Slope Drain (Runoff Conveyance Measure): Flexible tubing or conduit extending temporarily from the top to the bottom of a cut or fill slope for the purpose of conveying concentrated runoff down the slope face without causing erosion.

Temporary Stream Crossing: A bridge, ford, or temporary structure installed across a stream or water course for short-term use by construction vehicles or heavy equipment, intended to keep sediment out of the stream and avoid damage to the streambed.

Terrace: A flat bank, adjacent to the river in alluvial valleys created by the abandonment of the floodplain.

Thalweg: A line following the deepest part of the bed or channel of a stream.

Tide: The periodic rising and falling of the water that results from gravitational attraction of the moon, the sun and other astronomical bodies acting upon the rotating earth.

Tie-back: A variety of techniques used to secure the bulkhead, seawall, or revetment in place against the bank.

Tied In: An expression used to indicate that a revetment or dike is constructed to prevent or minimize streamflow between the structure and the bank.

Toe: Where the streambank meets the streambed.

Tombolos: Sand or gravel beaches which connect one (1) or more offshore islands to each other or to the mainland. The terms connecting bar, tie bar, and tying bar are synonymous.

Topsoiling: Preserving and subsequently re-using the upper, biologically active layer of soil to enhance final site stabilization with vegetation. Topsoiling should not be conducted on steep slopes. Stockpiled soil should be contained with sediment barriers, and temporary seeded for stability. Surfaces which will receive topsoil should be roughened just prior to spreading the soil to improve bonding. Spread topsoil should be lightly compacted to ensure good contact with the subsoil. Topsoil can act as a mulch, promoting final vegetation establishment, increasing water infiltration, and anchoring more erosive subsoils.

Training Walls: Walls constructed at the entrances of estuaries and rivers to improve navigability.

Undermining: The removal of lateral support at the base of a slope by scour, piping erosion, or excavation.

Updrift: The direction opposite that of the predominant movement of sediment along the shore. The side of a groin, jetty or other structure where sand accumulates.

Upland: A general term for land or ground that is higher than the floodplain.

Upland Plant: Plant naturally found in wetlands less than one (1) percent of the time.

Uprush: The landward flow of water up onto the beach that occurs when a wave breaks.

Vegetated Buffer: Vegetated areas separating a waterbody from a land use and its associated runoff. Vegetated buffers (or simply buffers) are variable in width and can range in function from vegetated filter strips to wetlands. Often serves as valuable wildlife habitat or corridors.

Vegetative Cuttings: Live, cut stems and branches of plants that will root when embedded or inserted in the ground.

Vegetated Filter Strip (Sediment Traps and Barriers): Created areas of vegetation designed to remove sediment and other pollutants from surface water runoff by filtration, deposition, infiltration, adsorption, decomposition, and volatilization. A vegetated filter strip is an area that maintains aeration as opposed to a wetland, which at times exhibits anaerobic soil conditions.

Vegetated Geogrid: Soil wrapped with a geotextile fabric and with live woody plant cuttings placed in between each soil/geotextile wrap.

Vegetative Measures: The use of live cuttings, seeding, sodding, and transplanting in order to establish vegetation for erosion control and slope protection work.

Vegetated Structures: A retaining structure in which living plant materials, cuttings, or transplants have been integrated into the structure.

Vegetative Rock Gabion: A structure built of metal wire baskets filled with rock and soil. These structures are then interplanted with woody plant material.

Velocity: The distance that water travels in a given direction during an interval of time.

Velocity Zone (V-Zone): A zone subject to velocity-water flooding during storms that have a 100-year recurrence interval. In coastal areas, the V-Zone generally extends inland to the point where the 100-year flood depth is insufficient to support a three (3)-foot high breaking wave.

Vernal Pool: Seasonally wet pool, most frequently wet in winter and spring and dry in summer.

Wale: Structural element of a bulkhead, fixed horizontally between the vertical piles on the seaward side and the sheet piles on the landward side.

Watercourse: A natural or man-made channel that conveys water.

Watershed: The land area that drains to a particular point or area in the landscape (i.e., to a pond, lake, river, etc.); the area drained by a given stream.

Water Level: The elevation of the free water surface of a body of water above or below any datum. Mean water level is the average water elevation at a particular place and time.

Water Table: The top of the saturated zone in soil or rock.

Wattle (Fascine): Originally meaning a structure built of woven branches, now sometimes used interchangeably with fascine.

Wavelength: The distance between successive inflection points, or other corresponding parts, in a series of meander bends.

Weephole: Opening left in a revetment or bulkhead to allow groundwater drainage.

Wetlands: Those areas that are inundated or saturated by surface water or ground water at a frequency and duration to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions; wetlands generally include swamps, marshes, bogs, and similar areas.

Wetted Perimeter: The length of the wetted contact between a stream of flowing water and the stream boundary, measured in a vertical plane at right angles to the direction of flow.

Wet Meadow: Grassland with waterlogged soil near the surface and open, standing water absent for most of the year. Woody plants are few or entirely absent.

Width/Depth Ratio: The ratio of bankfull surface width divided by the bankfull depth.

Willow (Woven) Check Dams: Woven Willow Check Dams are constructed from live, usually indigenous, willow material to control gully erosion. Woven willow check dams are usually constructed in channel bottoms of gullies that receive ephemeral or intermittent stream flow.

Willow Wattles: Woven bundles of woody branches typically from a species that is very rootable. This bundle is placed along the contour of a slope or streambank in order to reduce the length of the slope and provide vegetation as a buffer zone. They commonly have wood or live stakes to anchor the wattle in place.

Wingwall: The end portion of a bulkhead, seawall or revetment that cuts back in toward the bank, usually at a right angle to the main structure. The purpose of a wingwall is to help retard or prevent flanking.

APPENDIX B - REFERENCE SECTION

AWPI, 1981. *Standard Designs for Treated Timber Cribbing*. Washington, DC: American Wood Preservers Institute.

Barnhart, R.K. 1986. *The American Heritage Dictionary of Science*. Houghton Mifflin Company, Boston, MA.

Bolling, D.M., 1994. *How To Save A River, A Handbook for Citizen Action*. Island Press, Washington, D.C. and River Network, Portland, Oregon.

Coates, Donald, 1987. *Dictionary of Geology and Geophysics*. Dorothy Farris Lapidus, New York.

Dillaha, T.A., R.B. Renear, S. Mostaghimi, and D. Lee. 1989a. "Vegetative Filter Strips for Agricultural Nonpoint Source Pollution Control," *Transactions of the American Society of Agricultural Engineers*, 32(2).

Finlayson, M. and Moser, M., 1991. *Wetlands*. Facts on File Limited, Oxford, UK and New York, NY, Edited and Designed by Toucan Books Limited, London.

Federal Highway Adminstration, 1974. Standard specifications for construction of roads and bridges on Federal highway projects, FP74. Washington, DC.

Gray, Donald H. and Robin B. Sotir, 1996. *Biotechnical and Soil Bioengineering Slope Stabilization, A Practical Guide for Erosion Control*. New York. John Wiley & Sons, Inc.

Hammer, D.A., 1992., 1992. "Designing Constructed Wetlands Systems to Treat Agricultural Nonpoint Source Pollution." *Ecological Engineering*.

Hilfiker, W.K., 1972. Reinforced Concrete Cribbing. U.S. Patent #3,631,682 (January 4, 1972).

Hunt, R.L., 1980, "Two recent modifications of habitat development techniques in Wisconsin." In *Proceedings* of the Trout Stream Habitat Improvement Workshop. Asheville, N.C. November 3-6: 60-62.

Hunt, R.L. 1993, *Trout Stream Therapy*. The University of Wisconsin Press.

Hunter, C. J., 1991. *Better Trout Habitat: A Guide to Stream Restoration and Management*. Island Press, Washington, D.C.

Interagency, 1998. Stream Corridor Restoration: Principles, Processes, and Practices, Draft.

Johnson, A. W. and J. M. Stypula. Eds., 1993. *Guidelines for Bank Stabilization Projects in the Riverine Environments of King County*, King County Department of Public Works, Surface Water Management Division, Seattle, Washington.

Lancaster, T. and D.N. Austin, 1994. "Classifying Rolled Erosion-Control Products: A Current Perspective," Erosion Control Technology Council, Geotechnical Fabric Report, Industrial Fabrics Association International.

Lal, R. (Ed.), 1994. *Soil Erosion Research Methods*. St. Lucie Press, Delray Beach, Florida, Soil and Water Conservation Society, Ankeny, Iowa, 2nd edition.

Lowrance, R. R., S. McIntyre, and C. Lance. 1988. "Erosion and Deposition in a Field/Forest System Estimated Using Cesium-137 Activity." *Journal of Soil and Water Conservation*, 43(2).

McCullah, J., 1994. *Erosion Draw 2.0, Erosion and Sediment Control Manual for Computer-Aided Drafting*, Salix, Applied Earthcare.

Merriam-Webster, 1991. *Webster's Ninth New Collegiate Dictionary*. Merriam-Webster, Inc., Springfield, MA.

Mitsch, W.J., and J.G. Gosselink, 1986. *Wetlands*. Van Nostrand Reinhold Co., New York, NY.

Muncy, J.D., and J.C. Fischenich, E.A. Dardeau, 1996. *National Review of Corps Environmental Restoration Projects, IWR Report 96-R-27*, USACE Water Resources Support Center, Institute for Water Resources and Waterways Experiment Station. US Army Corps of Engineers.

Newbury, R.W. and Gaboury, M.N., 1993. *Stream Analysis and Fish Habitat Design; A Field Manual*, Newbury Hydraulics Ltd., The Manitoba Habitat Heritage Corporation, Manitoba Fisheries Branch, Gibsons, British Columbia, Canada.

Payne, N.F., 1992. *Techniques for Wildlife Habitat Management of Wetlands*, McGraw-Hill Publishing Company, New York, NY.

Peavy, H.S., D.R. Rowe, and G. Tchobanoglous, 1985. *Environmental Engineering*. McGraw-Hill Publishing Company, New York, NY.

Porter, D.R. and Salvesen, D.A. (Eds.), 1995. *Collaborative Planning for Wetlands and Wildlife*, Island Press, Washington, D.C.

Reeves, G.H. and T.D. Roelofs, 1982, "Rehabilitating and enhancing stream habitat: field applications." In Meehan, W. (ed.). "Influence of Forest and Rangeland Management on Andromous Fish Habitat in Western North America." USDA Forest Service. General Technical Report PNW-140.

Rosgren, D., 1994. *A Classification of Natural Rivers*. CANTENA, International Society of Soil Science.

Rosgren, D,. 1996. *Applied River Morphology*, Wildland Hydrology, pp. 8-15 - 8-20.

Scodari, P.F., C.C. Bohlen, and A. Srivastava of King and Associates, Inc., 1995. *Prototype Information Tree for Environmental Restoration Plan Formulation and Cost Estimation*, IWR Report 95-R-3, prepared for USACE Water Resources Support Center, Institute for Water Resources and Waterways Experiment Station, US Army Corps of Engineers.

Schuster, R. ., W.V. Jones, R.L. Sack, and S.M. Smart, 1973. A study and analysis of timber crib retaining walls. USDA Forest Service Final Report No. PB-221-447, 186 pp.

Seehorn, M.E., 1985, *Fish Habitat Improvement Handbook*. United States Forest Service, Southern Region, Technical Publication R8-TP7: 21 pp.

Shreffler, D.K., R.M. Thom, M.J. Scott, Wellman K.F., and M. Curran, 1995. *National Review of Non-Corps Environmental Restoration Projects*, IWR Report 95-R-12, prepared for USACE Water Resources Support Center, Institute for Water Resources and Waterways Experiment Station, US Army Corps of Engineers.

Thom, R.M., K.F. Wellman, 1996. *Planning Aquatic Ecosystem Restoration Monitoring Programs*, IWR Report 96-R-23, prepared for USACE Water Resources Support Center, Institute for Water Resources and Waterways Experiment Station, US Army Corps of Engineers.

United States Army Corps of Engineers, Institute for Water Resources, 1979. *Wetland Values; Concepts and Methods for Wetlands Evaluation*, Research Report 79-R1, USACE Water Resources Support Center, U.S. Army Corps of Engineers.

United States Army Corps of Engineers, Institute for Water Resources, 1982. *A Guide to the George Palmiter River Restoration Techniques*, Contributing Report 82-R1.

United States Army Corps of Engineers, Waterways Experiment Station, Environmental Laboratory, 1994. *Reservoir Shoreline Erosion and Revegetation Workshop*, PROSPECT Class.

United States Army Corps of Engineers, 1981a. Low Cost Shore Protection Brochure. USACE (DAEN-CWP-F), Section 54 Program, Washington, DC.

United States Army Corps of Engineers, 1981a. Low Cost Shore Protection , A Guide for Local Government Officials. USACE (DAEN-CWP-F), Section 54 Program, Washington, DC.

United States Army Corps of Engineers, 1981a. Low Cost Shore Protection, A Guide for Engineers and Contractors. USACE (DAEN-CWP-F), Section 54 Program, Washington, DC.

United States Army Corps of Engineers, Low Cost Shore Protection, A Property Owner's Guide, 1981a. USACE (DAEN-CWP-F), Section 54 Program, Washington, DC.

United States Army Engineer District, Galveston, 1989. "McFaddin Ranch Wetlands, Salt Bayou, Texas, Final Project Modification Report - Section 1135," US Army Corps of Engineers, Galveston District.

United States Army Engineer District, Seattle, 1993. "Sammamish River, Washington, Section 1135, Channel Modification Report, Project Modification Report and Environmental Assessment," US Army Corps of Engineers, Seattle District.

United States Army Engineer District, St. Paul, 1991. "Homme Reservoir, Walsh County, Minnesota, Section 1135, Project Modification Report," US Army Corps of Engineers, St. Paul District.

United States Department of Agriculture, 1992. "Soil Bioengineering for Upland Slope Protection and Erosion Control." Part 650, Chapter 18. Engineering Field Handbook.

United States Department of Agriculture, Natural Resources Conservation Service, 1996. "Streambank and Shoreline Protection," Chapter 16, Engineering Field Handbook.

United States Environmental Protection Agency, Region 10, 1994. "Partnerships & Opportunities in Wetland Restoration," Proceedings of a Workshop, Seattle, Washington.

Watson, Chester C., Abt, Steven R., and Derrick David, 1997. "Willow Posts Bank Stabilization," *Journal of the American Water Resources Association, Formerly Water Resources Bulletin*, Volume 33, No.2, pages 293-300.

White, R.J. and O.M. Brynildson, 1967. "Guidelines for management of trout stream habitat in Wisconsin." Wisconsin Department of Natural Resources. Technical Bulletin 39: 65 pp.

Zenner, G.G., LaGrange, T.G., Hancock, A.W., 1992. "Nest Structures for Ducks and Geese." Iowa Department of Natural Resources, Des Moines, IA. Jamestown, ND.

APPENDIX C - WEB SITES

The following sites with (R) were used as research for this book. The following sites with (O) are sites that were discovered and may be of interest in this area of research.

Alaska Department of Fish and Game – (R)
http://www.state.ak.us/local/akpages/FISH.GAME/habitat/hab_home.htm

American Heritage Rivers – (O)
http://www.epa.gov/owow/heritage/rivers.html

"Branching Out With Bioengineering." - (O)
http://www.gmu.edu/bios/Bay/journal/96-05/bioengin.htm

Bureau of Indian Affairs – (O)
http://www.doi.gov/bureau-indian-affairs.html

Bureau of Reclamation – (0)
http://www.usbr.gov/

Bureau of Land Management – (O)
http://www.blm.gov/

Coastal America – (R) http://www.csc.noaa.gov/coastalamerica/

Elwha River, Washington, Ecosystem Restoration Implementation – (O)
http://www.nps.gov/planning/olym/drftsum/elwha.htm

Environment Australia, Coastline Management Manual, New South Wales Government, New South Wales, Sept 90 – (R)
http://www.erin.gov.au/portfolio/esd/coast_marine/coast_manual/index.html

Environmental Protection Agency – (R)
http://www.epa.gov/

Environmental Protection Agency, "National Estuary Program: Bringing Our Estuaries New Life." - (R) http://www.epa.gov/nep/nepbroc.html

Environmental Protection Agency, Office of Wetlands, Oceans & Waterways, Wash., D.C. – (R) http://www.epa.gov/OWOW

Environmental Studies, The Academy for the Advancement of Science and Technology, Bergen County, NJ. – (O) http://www.bergen.org/AAST/Projects/ES/

Erosion Draw 2.0 – (R)
http://erosiondraw.com/samples.htm

Federal Emergency Management Agency – (O)
http://www.fema.gov/

Fish and Wildlife Service – (R)
http://www.fws.gov/

Forest Service –(R)
http://www.fs.fed.us/

Geo-Civ Products, Inc – (R)
http://geo-civ.com/

Great Lake Projects – (O)
http://www.cisti.nrc.ca/cisti/journals/occasional/op01/abstract.html

Habitat Restoration Group – (O)
http://www.cruzio.com/%7Ehrg/

Horizon Environmental Services, Inc. - Austin- Beaumont-Shreveport – (O)
http://www.horizon-esi.com/horz1.htm

International Erosion Control Systems – (R)
http://www.iecs.com

Land and Water Magazine – (R)
http://www.landandwater.com/

"Life on the Edge," Anchorage Daily News – (O)
http://www.adn.com/TOPSTORY/T9711021.HTM

"Managing Aquatic Plants in Minnesota Lakes" - (O)
http://www.ent.agri.umn.edu/cues/pond.htm

National Oceanic and Atmospheric Administration (NOAA) – (R)
http://www.noaa.gov/

National Park Service – (O)
http://www.nps.gov/

Natural Resource Conservation Service – (R)
http://www.nrcs.usda.gov/

Northern Prairie Wildlife Research Center, Jamestown, North Dakota, United States Geological Survey – (R) http://www.npsc.nbs.gov/index.htm

North Carolina Cooperative Extension Service, "Waterfowl on Prior Converted Wetlands in North Carolina." - (O)
http://www.ces.ncsu.edu/nreos/wild/wetland.html

Pennsylvania Department of Environmental Protection – (O)
http://www.dep.state.pa.us/dep/deputate/enved/Can_Do/streambank.htm

"Restoring Crane Habitat Along the Platte River of Nebraska" - (O)
http://www.hort.agri.umn.edu/h5015/weddle.htm

"Riparian Ecosystem Creation and Restoration: A Literature Summary" - (R)
http://www.npsc.nbs.gov/resource/literatr/ripareco/costs.htm

River Research and Design, Inc. Stream Crossing Protection and Current Alignment/Redirection Services – (R)
http://www.r2d-eng.com/STREAMS.HTM

StreamNet On-Line, The Northwest Aquatic Information Network – (R)
http://www.streamnet.org/projectdata.html

Tennessee Valley Authority – (O)
http://www.tva.gov/

The Bioengineering Group, Inc. - Salem, Massachusetts – (R)
http://www.bioengineering.com/glossary.htm

The Global Eco-Village Network – (O)
http://www.gaia.org

United States Geological Survey – (O)
http://www.usgs.gov/

United States Army Corps of Engineers – (R)
http://www.usace.army.mil/

United States Army Corps of Engineers - Low Cost Shore Protection – (R)
http://sparky.nce.usace.army.mil/shore.protection/lcsphmpg.html

United States Army Corps of Engineers, Institute for Water Resources, Technical and Research Division. – (R)
http://www.wrsc.usace.army.mil/iwr/tard/tard.htm

United States Army Corps of Engineers, Waterways Experiment Station – (R)
http://www.wes.army.mil/

United States Bureau of Reclamation Sedimentation and River Hydraulics Group – (O)
http://www.usbr.gov/srhg/index.html

United States Department of Agriculture – (O)
http://www.usda.gov/

United States Department of Agriculture, Natural Resources Conservation Service, Watershed Technology Electronic Catalog, Washington, D.C. – (O)
http://ftp.wcc.nrcs.usda.gov/wtec/

United States Department of Commerce – (O)
http://www.doc.gov/

United States Department of Interior – (O)
http://www.doi.gov/

Virginia Cooperative Extension, Knowledge for the Commonwealth - "Pond Construction: Some Practical Considerations" - (R)
http://www.ext.vt.edu/pubs/fisheries/420-011/420-011.html

Watershedss, Water Quality Decision Support System, North Carolina State University and Pennsylvania State University – (O) http://h2osparc.wq.ncsu.edu/index.html

Watershedss; Water, Soil, Hydro-Environmental; Decision Support System, North Carolina State University – (O) http://h2osparc.wq.ncsu.edu/index.html

"What You Can Do To Control Erosion And Protect Your Property." - (R)
http://www.abag.ca.gov/bayarea/enviro/erosion/eyoudo.html

APPENDIX D - OTHER RELATED REPORTS

***Prototype Information Tree for Environmental Restoration and Plan Formulation and Cost Estimation*, IWR Report 95-R-3, March 1995** - This report focused on three specific objectives: 1) developing a prototype information tree structure to provide and organize data and information useful for environmental restoration plan formulation and cost estimation; 2) describing the content of the tree branches and their linkages; and 3) beginning the process of building the tree database, and identifying additional data sources and data deficiencies with respect to its more complete implementation.

The report describes the conceptual development of an information tree to assist in the design of environmental restoration projects. It examines and illustrates various environmental assessment techniques used by project planners to identify site deficiencies with respect to project goals. It focused on developing the "roots" of the tree which link the results of environmental assessments (i.e., target variables) with the main stem. A primary consideration for development the tree structure was how site-specific factors might be reflected in the various tree branches.

***National Review of Non-Corps Environmental Restoration Projects*, IWR Report 95-R-12, December 1995** - This report compiled management measures, engineering features, monitoring features, and detailed costs for a representative sample of non-USACE environmental projects or engineering projects with environmental features. The information from this report can be used to assist planners in the following: 1) identifying potential environmental variables that can be manipulated to improve environmental outputs; 2) identifying alterative management measures for modifying those variables; 3) identifying the various engineering features or components of those management measures; 4) determining the associated probability of success of alternative management measures; and 5) estimating their costs.

***Planning Aquatic Ecosystem Restoration Monitoring Programs*, IWR Report 96-R-13, November 1996** - This report provides a systematic approach to planning, implementing, and interpreting monitoring programs for restoration projects. This report will discuss how a monitoring program proceeds from identification of goals through selecting monitoring methods, and finally to interpreting and dissemination of results. The use of monitoring results to implement corrective actions are also described. This report is not a "how to" manual of the specifics of sampling, sample processing, statistical processing, statistical analysis, etc., but rather a guide to developing a monitoring program for aquatic restoration.

The report is directed to USACE planners to help them identify factors to consider in a monitoring program, and to design and implement an efficient, cost-effective program. The information may also be helpful to others involved in mitigation and restoration projects, including resource managers, developers, aquatic scientists, landscape architects and engineers.

***National Review of Corps Environmental Restoration Projects*, IWR Report 96-R-27, November 1996** - This report provides descriptive information for water resource planners and managers concerning the engineering features of recently completed or on-going (at the time of report writing) Corps environmental restoration projects. For each project, information is provided concerning: its general location, the resource problems being addressed, objective(s), management measures, outputs, and estimated total costs. The projects selected represented a cross-section in terms of geographical location, legislative authority under which undertaken, and types of engineering features recommended. This report is a companion document to IWR Report 95-R-12.

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*
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13. ABSTRACT (Maximum 200 words) This report was started under the Evaluation of the Environmental Investments Research Program and completed under the Decision Support Technologies Research Program. The purpose of this document is to identify and describe examples of various environmental engineering features or management measures and their components. The objective is to stimulate planners and others as to the types of management measures that are available. This document is not intended to be a design manual, but rather to provide sufficient information to stimulate plan formulation and assist planners in identifying what's out there and to "visualize" how an engineering feature(s) may be applicable in their project.			
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